CANADA

PRIME MINISTER • PREMIER MINISTRE

gy consumption in building
ems accounts for almost
ty-five per cent of Canada's
gy demand. We must, as
gy conscious Canadians,
ove the efficiency of this
gy use. Even if availability
ufficient energy resources
be assured, energy costs will
inue to increase and good
omic management will dictate
eased efficiencies be found.

nd it very encouraging there-
, that professionals, such as
itects, are developing
rmation of the type presented
his manual. The Federal
rnment believes it is in the
onal interest to act as
lyst for private sector energy
ervation initiatives and thus
financially supported this

manual leads the way towards
design and operation of energy
icient buildings for the future.
e its preparation is an
ntial initiative, I hope it
be widely used in training
professionals and support
efforts of those already in
workplace.

his is accomplished, all
dians can look forward to
ergy secure future and energy
sufficiency will be more
ly achieved by 1990.

La consommation énergétique dans les bâtiments représente presque 35% de la demande canadienne. Sensibilisés comme nous le sommes tous au Canada à ces questions, nous devons rentabiliser l'utilisation de cette forme d'énergie. Même si un approvisionnement suffisant en ressources énergétiques peut être assuré, les coûts de l'énergie continueront quand même d'augmenter et une saine gestion économique commande d'en rentabiliser l'emploi.

Que ces professionnels que sont les architectes diffusent des informations du type présenté dans ce manuel est très encourageant, à mon avis. C'est parce qu'il croit agir dans l'intérêt national en jouant le rôle de catalyseur des mesures d'économie d'énergie dans le secteur privé que le gouvernement fédéral a accordé un soutien financier à ce projet.

Cet ouvrage ouvre la voie à la conception et à la construction d'immeubles consommant peu d'énergie. Cet outil - indispensable s'il en est un - servira, du moins je l'espère, à former d'autres professionnels et à appuyer les efforts de ceux qui sont déjà à l'oeuvre.

Alors, les Canadiens n'auront pas à craindre pour leur avenir énergétique et l'objectif qu'ils se sont fixés de parvenir à l'autarcie d'ici 1990 sera plus facilement atteint.

Contents

The aim of this Handbook is to foster the sensible use of our natural resources in the construction and operation of buildings. It is a book for builders, by builders. The term is used in its broadest sense Architects, engineers, planners, economists and other allied professionals have provided the text They write from a background of extensive practical experience in their various fields. As a result, in the following pages we see a reflection of the many disciplines which, of necessity, now interact in the design and planning of individual buildings and in the environment which they create

The co-operation of our invited authors (thirty-four in all) which made this document possible is also symbolic of the collective effort which is vitally necessary for the achievement of the objectives which the Handbook promotes

Effective decisions regarding energy-conserving building design cannot be made by any one profession alone, working in isolation There is no growth in a vacuum We have a sufficiently large legacy of energy-inefficient buildings, some regrettably of recent origin, to substantiate that particular point

All involved in building, in one way or another, influence and in turn are influenced by others Architects, particularly, in their role as synthesizers must seek to recognize and understand these relationships Design decisions and related engineering, planning and economic implications interface like bricks and mortar It is necessary that they, too, be based upon a firm foundation.

While intended primarily for Canadian architects, the contents of this volume will be of value to all involved in designing, developing and constructing energy-conserving buildings and communities At the present time the built environment, including transportation, accounts for almost two-thirds of our nation's total energy consumption The opportunities for conservation are clearly described by our authors but they do not attempt to prescribe restrictive design criteria or propose standards and codes. This is not the time to stifle innovation but to nourish it Consequently, readers should not look for 'perfect' solutions engraved in stone—on the contrary, a loose leaf format was selected for the Handbook so that up-dated or additional insertions will be possible as new technologies develop More importantly though, they will discover in this Handbook a solid base of information which will assist them in developing their own solutions to particular and specific problems

Energy is defined as the capacity to do work. Energy conservation is the elimination of energy waste so that the work expended may achieve the most useful and beneficial results It is hoped that the RAIC Energy Conservation Design Resource Handbook will help architects and their colleagues to increase their capacity to work, creatively and knowledgeably, towards the construction of buildings, and a built environment, which make considerate use of our natural resources and which fulfill the needs and aspirations of our times

Howard V. Walker,
Executive Editor.

Acknowledgements

This volume is the largest project of its kind to be undertaken by the RAIC and acknowledgements are due many people who gave generously of their time and expertise in resolving its complexities.

Particular mention must be made of the role played by Professor Mirko Macalik with whom the idea originated, who rooted it firmly and diligently nurtured its growth. Special recognition is also due Robbins Elliott, executive vice-president, RAIC, for his solid support and efficient attention to the many administrative details involved in the production of this Handbook.

The RAIC Energy Task Force and the Advisory Board had the responsibility of determining the scope of the project, of organizing its financing and steering it to completion Their members were as follows

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Sun Oil
Dome Petroleum
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Grateful acknowledgement is also made to the following

American Institute of Architects for permission to reprint material from *A Survey of Passive Solar Buildings* 1978

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McGraw-Hill Book Company for permission to reprint material from *Handbook of Air Conditioning System Design* by Carrier Corporation © 1960

Ontario Ministry of Energy for permission to reprint material from a contract entitled *Passive Solar Heating Studies*, 1979

The TRANE Company, La Crosse W1 for permission to make use of illustrations from *Conserve Energy by Design*

Yale University Press for permission to reprint illustrations from *Southwestern Archeology by Alfred V. Kidder*, Yale University Press, New Haven © 1924, rev 1962.

Substantial portions of the following text have been contributed by Canadian engineering firms or individuals and this Handbook is endorsed by the Association of Consulting Engineers of Canada and the Canadian Council of Professional Engineers.

H.V.W.

1.0 Regulations

The land area of Canada is contained approximately within latitudes 40°S to 65°N and longitudes 60°E to 120°W, comprising an area of 9 220 975 km^2.

Regulations and guidelines prepared by the federal and provincial governments relating to energy conservation reflect the climatic diversity of this vast region and also the particular needs of their constituents

Section 1 0 has been left vacant so that readers may insert in this space copies of relevant government documents which pertain to the particular locations in which they practise

2.0 Environmental Design Factors

Contents

*Atmospheric Environment Service, Fisheries and Environment Canada, Ontario Region

2.1 External Spaces and Climate

2.1.1 Climatic Factors in Energy Utilization

Humans require certain temperature and humidity levels in order to be comfortable and the limits of this comfort range have been defined in bioclimatic charts, such as the one shown in **Figure 2.1.1-1**. Buildings are intended to provide their occupants with these optimum conditions even though we live in a climate where the temperatures are too cold in the winter and too hot in the summer

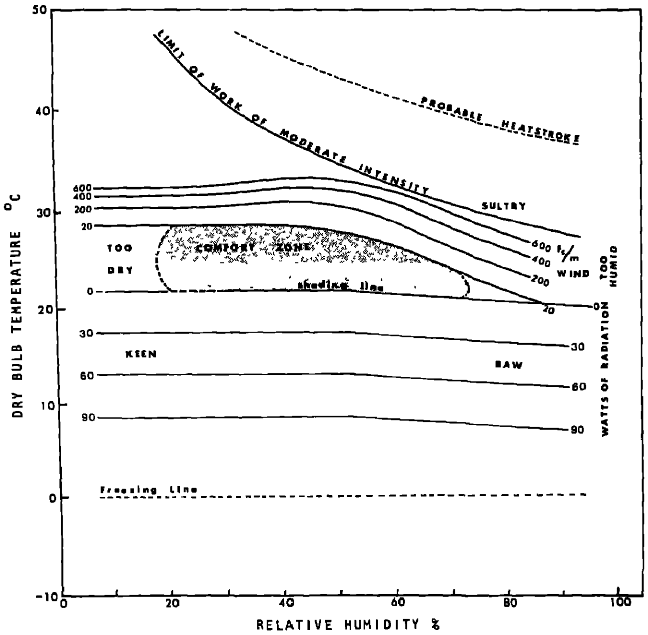


Figure 2.1.1-1[1]
Bioclimatic chart showing the effect of temperature and humidity on comfort[1]

Human comfort inside buildings is strongly influenced by the temperatures, winds and, to a lesser extent, by the humidity outside the building The rate at which heat is lost from a building is dependent on a number of factors including

- the difference between the temperature inside and outside (This temperature differential will affect the rate at which heat is radiated away from the building The radiant heat loss will also depend on the material and colour of the outside wall)
- the rate at which air from inside the building infiltrates the openings in the walls and escapes outside the building
- the rate at which the forced convection currents in the immediate vicinity of the building transfer heat from the walls and roof
- the reductions in the efficiency of cooling equipment resulting from the location of ventilation inlets and exhausts in places where the wind either causes a recycling of the exhaust gases or produces pressure gradients which affect the efficiency of the fans

The importance of these individual factors depends on the type of building being considered

Other factors contribute to the heat inside a building For example, the sunlight falling on the roof and wall surfaces as well as internal heat sources such as lights, electrical appliances and humans All tend to raise inside temperatures

2.1 External Spaces and Climate

Table 2.1.1-T_1 outlines the major heat losses associated with buildings of different types in Canada

HEAT LOSS FROM BUILDINGS				
Building Type	Infiltration	Transmission of Heat from Walls by Convection	Mechanical Cooling Systems Efficiency	Radiation Heat Loss/Gains from Walls
Office building	Neg	Sig	Sig	Sig
Residential low-rise	Very* Sig	Neg	Neg	Very* Sig
Residential high-rise	Very Sig	Sig	Sig	Sig

Neg —Negligible (less than 3% of the total energy loss)
Sig —Significant (5% 15% of the total energy loss)
Very Sig —Very significant (25% 30% of the total energy loss)
*Very sensitive to building orientation

Table 2 1 1-T_1
Influence of major building types on heat loss[1]

By enhancing the heating produced by insolation and by conserving more of the internal heat releases it is possible for building owners to develop their own energy conservation programs

The influence of climate on individual buildings, or groups of buildings, is a recurring theme throughout this Handbook The particular characteristics of the Canadian climate are discussed in detail in **Sections 2.1.2 to 2.1 5** which follow

2.1.2 General Climate

The climate of Canada is influenced by a number of topographical controls which interact in complex ways. Consequently, Canada's climate has large regional differences In the most western parts of the country, the cool, moist climate results from the influences of the Pacific Ocean and the Rocky Mountains Further to the east, in the Prairie provinces, the climate is dry with very hot temperatures in the summer and extreme cold in the winter The southern parts of Ontario are invaded by tropical air from the U S A and the Gulf of Mexico in summer while winters are not quite so cold as in the Prairies Meanwhile, the Atlantic Provinces are frequently inundated with cold air and remnants of storms from the west or southwest Finally, in the Arctic, the lack of incoming radiation during the winter and the year round ice cover result in a very harsh climate

Added to these topographical controls are the complex effects of the upper air circulation. Several kilometres above the earth is a band of strong westerly winds which controls the motions of storms at the surface This band moves northward in the summer and southward in the winter. As a result, cold air is brought down from the Arctic over central Canada in the winter while the warm air from the southern U.S.A. is incorporated into storm systems and brought northward into Canada during the summer.

2.1 External Spaces and Climate

In the following section, maps showing the distribution of a number of climatic parameters across Canada are presented and then a number of site-specific graphs for Metropolitan Toronto These graphs are intended to illustrate the types of analysis that can be used in planning energy conservation programs and in designing energy efficient buildings

Detailed national and regional climatological analyses may be found in a large number of publications A listing of the major climatological publications is included in this Handbook

2.1.2.1 Heating Degree Days and Temperatures

The heating demand at different locations in Canada is commonly assessed by studying the distribution of heating degree days (HDDs) The number of HDDs accumulated on a given day is defined as the difference between the daily mean temperature for that day and an 18°C base temperature

Figure 2.1.2.1-1 shows the distribution of HDDs for Canada According to this map, the heating demand is lowest in the southwestern parts of B C and Ontario It must be recognized that the scale of this map prohibits an accurate representation of the distribution of HDD values in the mountainous areas of B C As would be expected, there is a north-south gradient, values being as large as 13 500 in the North and as small as 3500 in the South. Very strong spatial gradients occur near the oceans and over mountainous terrain The seasonal variation in heating demand indicates that, on the average, the demand is largest during January.

The HDD distribution is dependant on the distributions of temperature **Figures 2.1.2.1-2** and **2.1.2.1-3** show the distribution of mean daily temperatures for the months of January and July respectively

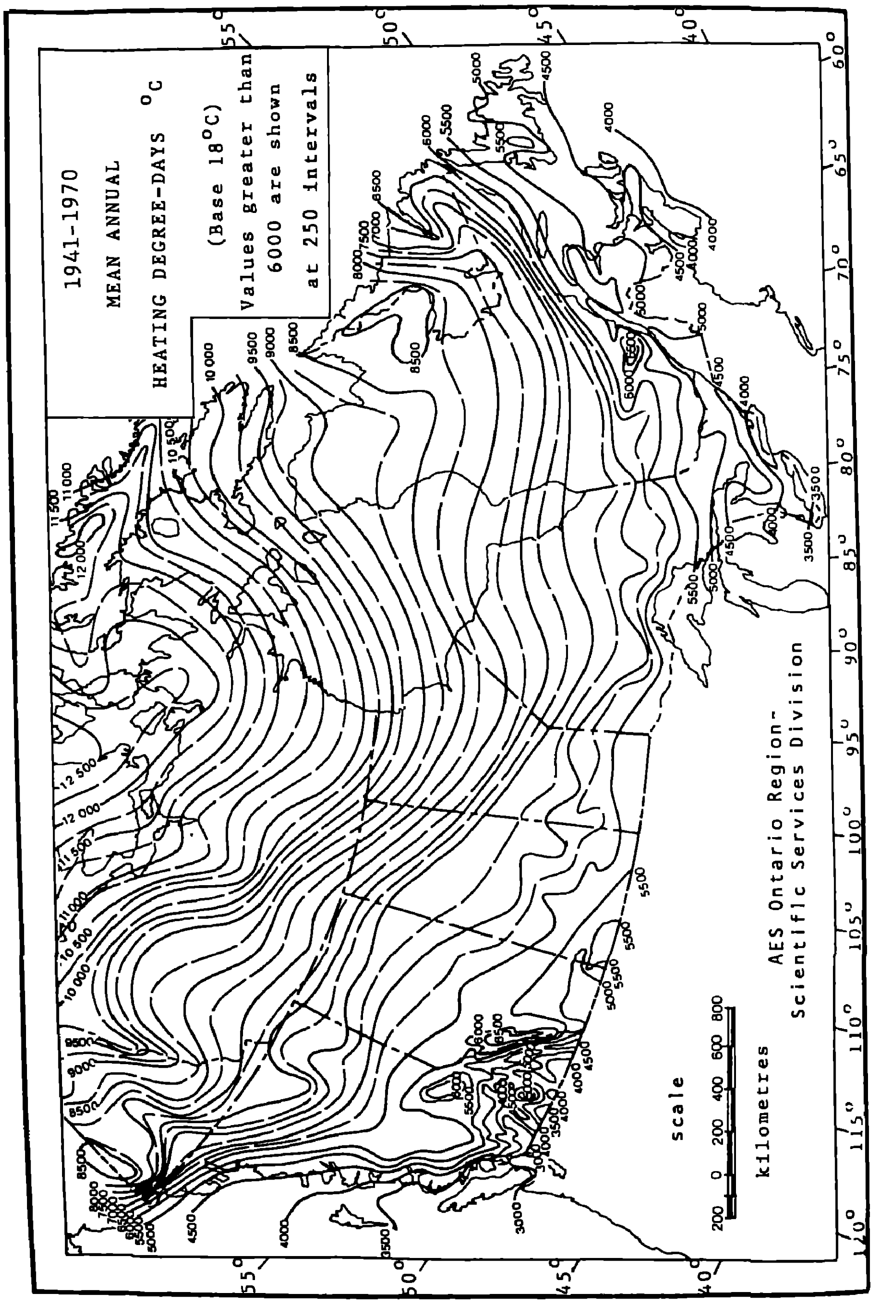
According to these maps, the average annual temperature in Canada varies with latitude being warmest in the south and coldest in the north Exceptions occur in the mountainous areas of B C and along the Pacific coast where the isotherms tend to be parallel with the coast and the mountain ridges At most Canadian locations the coldest temperatures occur during the months of January or February and the warmest during July

The greatest annual average temperature range occurs in very continental areas including the Arctic and in an area extending from the northern Yukon southeastward into northern Ontario and central Quebec The smallest annual temperature range occurs along the south coast of Newfoundland, and along the coastal areas of Nova Scotia and British Columbia where the moderating effects of the nearby oceans are most significant

Figure 2.1.2.1-4 shows the sensitivity of the heating demand to variations in temperature A graph similar to this for a given location can be used to assess the effect of a variation in temperature during a very cold or abnormally warm year

Climatological data which show the year-to-year variations in temperature and heating degree days are available from the specialists listed in **Table 2.1.2.1-T_1**. **Section 2.1.2.6** shows the variability of these parameters for Toronto

2.1 External Spaces and Climate



2.1 External Spaces and Climate

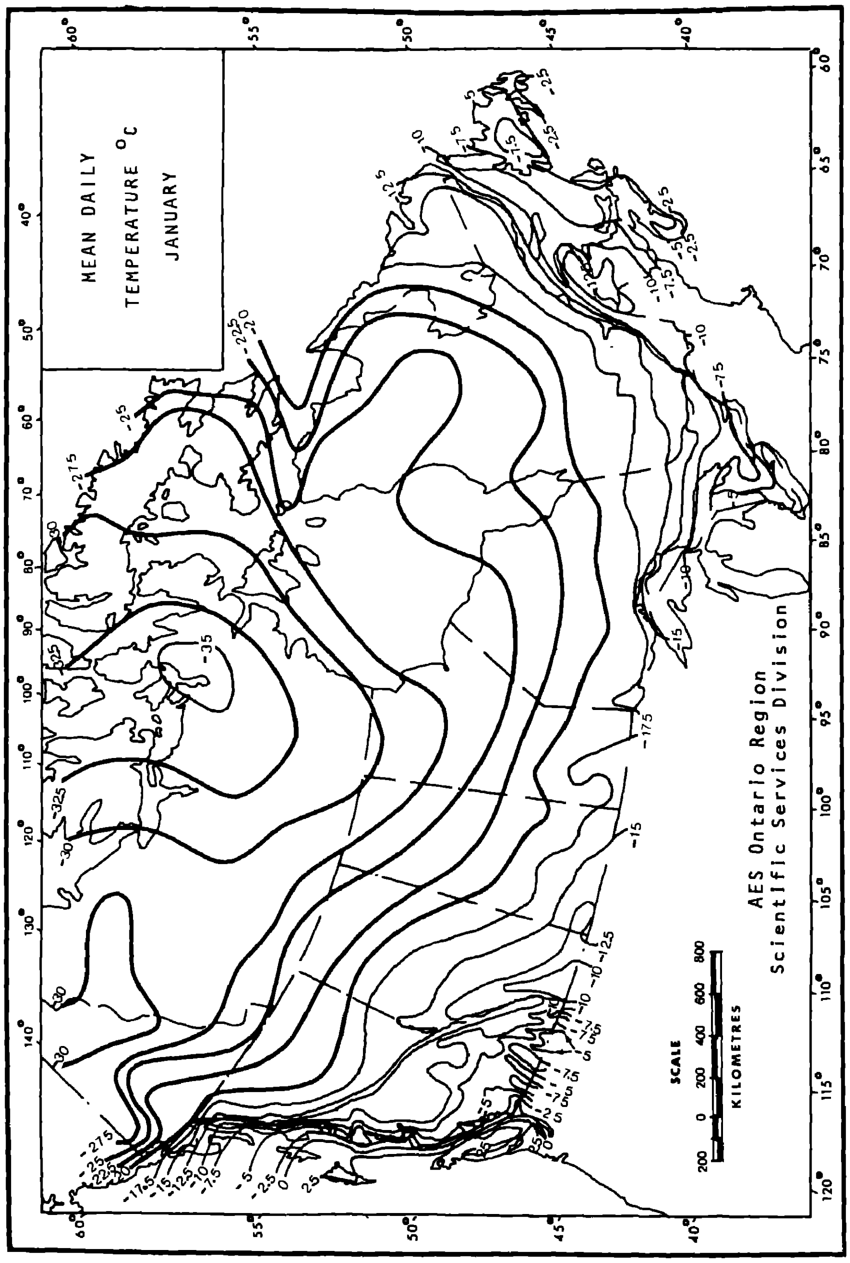


Figure 2.1.2.1-2

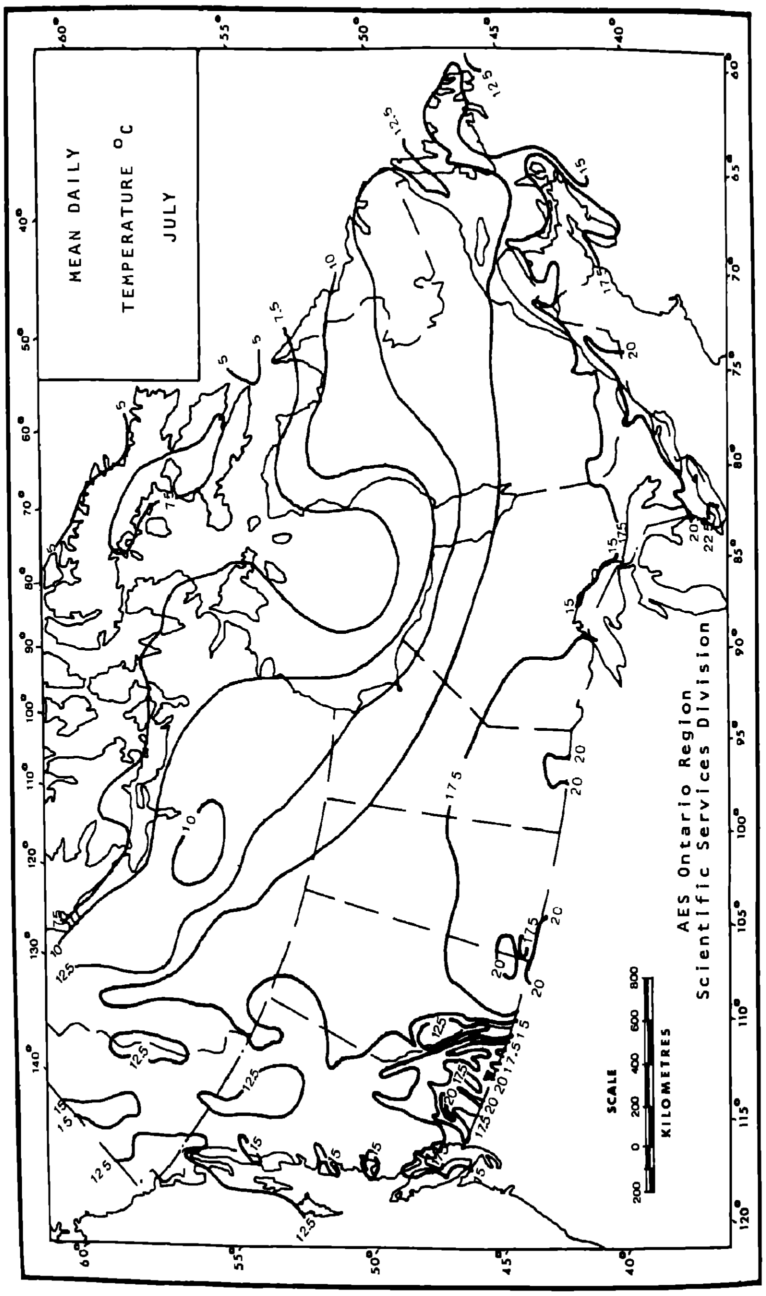


Figure 2.1.2.1-3

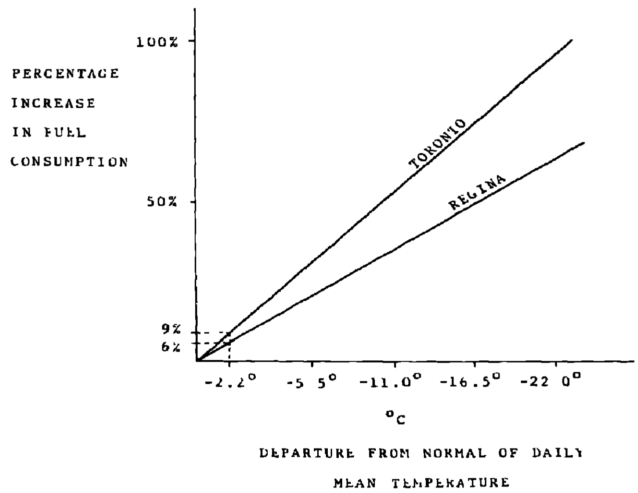


Figure 2.1 2 1-4
Changes in heating demand resulting from variation in mean daily temperature (based on HDD normals for Jan , Feb and March)

The map of mean July temperatures shown in **Figure 2.1.2.1-3** indicates that the warmest temperatures occur in Prairie provinces The map also shows areas where the temperatures exceed 24°C for more than 250 hours per year If we assume that 24°C represents the lowest temperature at which air conditioning is used, then the shaded areas represent those parts of Canada with the largest requirements for air conditioning

The requirements for air conditioning can also be assessed by an examination of other measures of discomfort Masterton and Richardson[3] computed the humidex for a number of Canadian locations Humidex values are determined by taking the dry bulb temperature and adding a fraction of the vapour pressure It was found that the highest values of humidex occured in July in south-western Ontario although the values were also quite large in Ottawa and Montreal

Figure 2.1.2.1-5 shows the diurnal variation of average hourly humidex values for 5 locations during July According to this graph, the humidex values are greatest at any hour of the day in Windsor. If one accepts a threshold for the humidex of 28°C (equivalent to a temperature of 24°C and a relative humidity of 55%) as the point where people turn on their air conditioners then air conditioning will be used for 11 hours per day in Windsor during July. The graph also indicates that humidex values in Winnipeg are less than the values in southern Ontario By using Masterton and Richardson's statistics[4] it is possible to calculate the number of hours per year when any base humidex value is exceeded.

The normal diurnal temperature variation during the summer months can be used as an indicator of the potential of air for natural cooling. **Figure 2.1.2.1-6** shows the distribution of average temperature ranges (maximum-minimum) across Canada for July. The map indicates that temperature ranges exceed 15°C for locations in mountainous terrain and/or locations where the air is relatively dry. On the other hand, temperature ranges are smaller near oceans or other large bodies of water

2.1 External Spaces and Climate

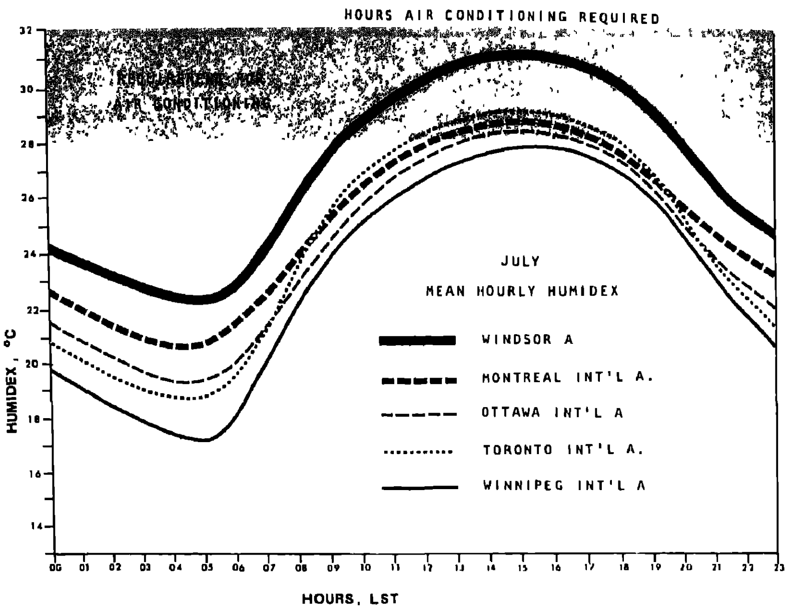


Figure 2 1 2.1-5
Diurnal variation of average annual humidex values for five locations

CONTACTS FOR FURTHER DATA

REGIONAL OFFICES:

Director, **Pacific Region**
Atmospheric Environment Service
Bordignon Building
1200 West 73rd St
Vancouver, B C V6C 1A1
Attn Scientific Services Division

Director, **Western Region**
Atmospheric Environment Service
Argyll Centre
6325—103 Street
Edmonton, Alberta T6H 5H6

Director, **Central Region**
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Winnipeg, Manitoba R3C 3V4
Attn Scientific Services Division

Director, **Ontario Region**
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Attn Scientific Services Division

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Atmospheric Environment Service
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Ville St-Laurent, P Q H4M 2N6
Attn Scientific Services Division

Director, **Atlantic Region**
Atmospheric Environment Service
P O Box 5000
Bedford, N S BON 1B0
Attn Scientific Services Division

NATIONAL HEADQUARTERS·

Assistant Deputy Minister
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario M3H 5T4
Attn Applications and Impacts Division

Table 2.1.2.1-T_1
Listing of addresses of regional and headquarters contacts for site-specific data on regional climatic maps for use in planning energy conservation programs

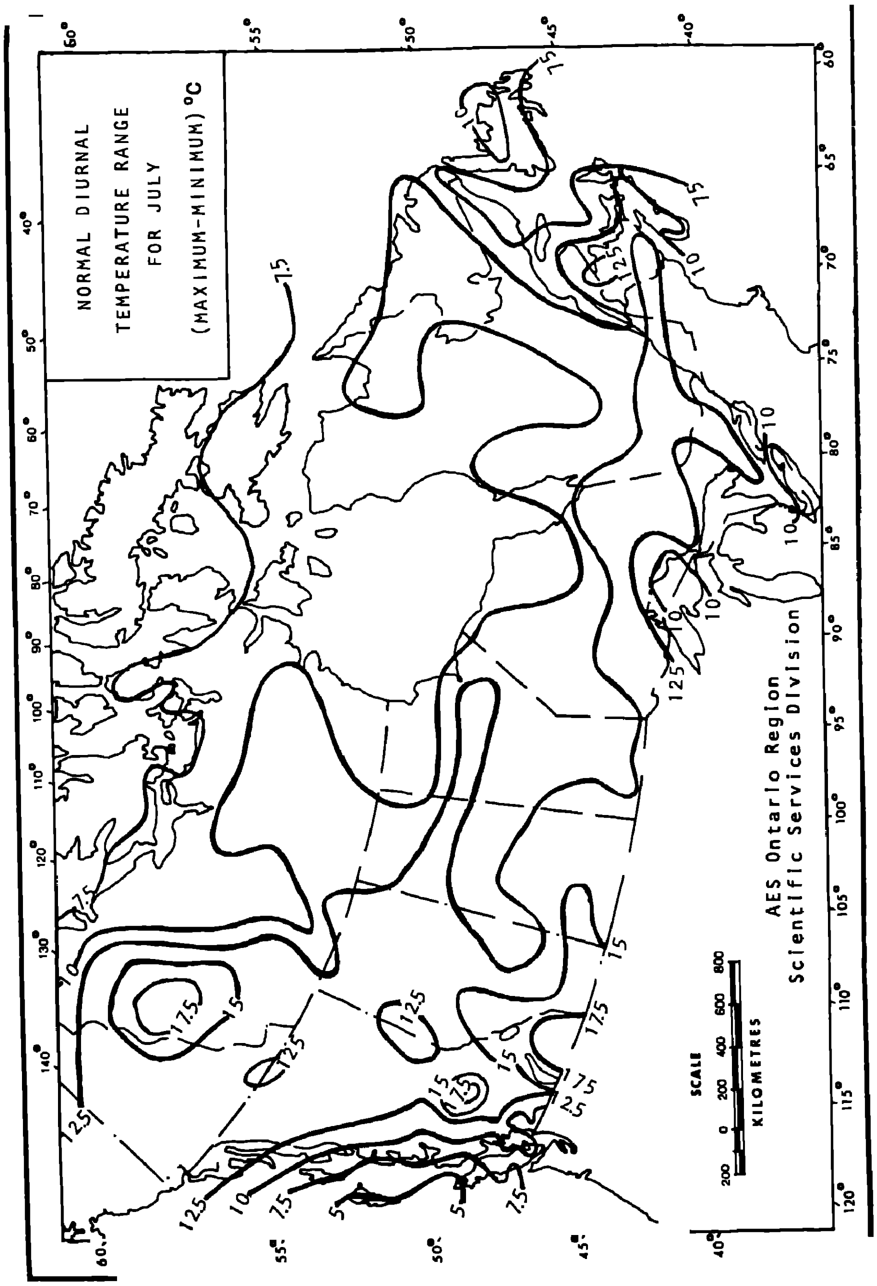


Figure 2.1.2.1-6

2.1.2.2 Solar Radiation and Sunshine Data

The availability of solar radiation must also be assessed as one step in developing a comprehensive energy conservation program. Solar radiation amounts at a given location provide an indication of the energy available for both active and passive solar heating systems. **Figure 2.1.2.2-1** shows the distribution of average daily global solar radiation for stations throughout Canada Global solar radiation is made up of two components. a direct beam component which is recorded during the daylight hours when no clouds are obscuring the sun and a diffuse component whose intensity increases as the cloud or haze for a given solar elevation become more frequent in the sky

The average daily global solar radiation varies with latitude in Canada between September and February During the spring and summer, from March to August, the Prairies tend to receive more radiation than the eastern or western parts of Canada

The availability of incoming solar radiation can be related to the potential for passive solar heating. According to Milne and Givoni[5], on a south-facing slope under clear sky conditions, 19 3 MJ/m² would be received at 32°N and 14 73 MJ/m² would be received at 48°N If this energy is captured by 18 6 m² of south-facing glass, then comfortable temperatures could be maintained per day with passive solar heating alone for a building of 92 9 m² at temperatures of 6.1°C at 32°N and 9.4°C at 48°N This assumes an overall system efficiency of 0.33 for collection, storage and distribution of the passive solar heating.

The contribution of passive solar heating is most useful in the winter when the temperatures are coldest The annual contribution of passive solar heating is largest in the regions shown in **Figure 2.1.2.2-2** where the highest monthly mean maximum temperatures are below 18°C and heating is required in all 12 months The map is derived from sunshine hours and monthly mean maximum temperatures.

Figure 2.1.2.2-3 shows the average daily global solar radiation on a horizontal surface during January

To determine, on a day with an average amount of solar radiation, the minimum temperature for which passive solar heating can meet

DAILY TOTAL SHORT WAVE RADIATION

[illegible]tation	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
[illegible] B.C.	1.730	1 467	1 085	0 767	0 575	0 498	0 520	0 677	0 975	1 321	1 620	1 803
[illegible], Alta.	2.750	1 993	1.384	0 896	0 631	0 541	0 574	0 747	1.089	1 710	2 485	3 089
[illegible] Alta.	2.559	1 863	1.281	0 812	0 581	0 497	0 526	0 698	1 024	1 573	2 206	2.776
[illegible]rent, Sask.	2.561	1 880	1 306	0 820	0.579	0.497	0 524	0.693	1 021	1 585	2 218	2 761
[illegible] Man.	3.983	2 534	1.689	1.092	0.725	0.606	0 644	0 828	1.146	1 735	2 970	4.813
[illegible] Man.	2.533	1 876	1 283	0 817	0 579	0 495	0 527	0 685	0 990	1 452	1 961	2 604
[illegible] Ont.	1.797	1.460	1 048	0.697	0.507	0 449	0.459	0 593	0 844	1 198	1 440	1.786
[illegible] Ont.	1.820	1.529	1 110	0.711	0.526	0 456	0.479	0.620	0 877	1.232	1 498	1 899
[illegible] Que.	1.875	1.497	1 030	0.711	0.526	0.461	0.485	0 618	0 881	1.263	1 613	1.897
[illegible] N.B.	1.984	1.584	1.072	0.712	0 540	0 470	0 497	0.629	0 882	1.250	1 581	2 039
[illegible]	1.716	1.405	1.016	0.699	0 535	0.461	0 491	0.612	0.861	1 222	1.525	1.717

[illegible] the factors which daily total short wave radiation values measured on a horizontal surface must be multiplied by [illegible] daily short wave radiation on a vertical south-facing surface.[7]

2.1 External Spaces and Climate

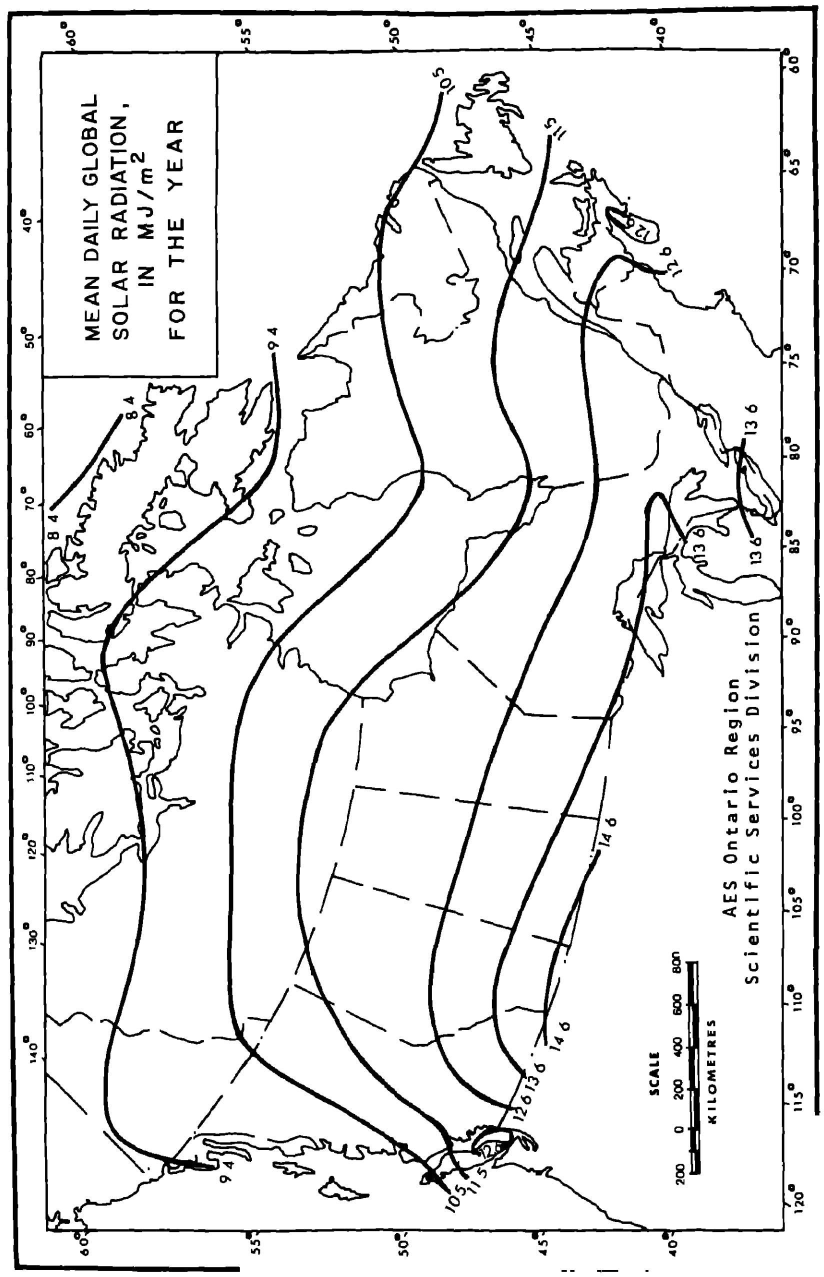


Figure 2.1.2 2-1

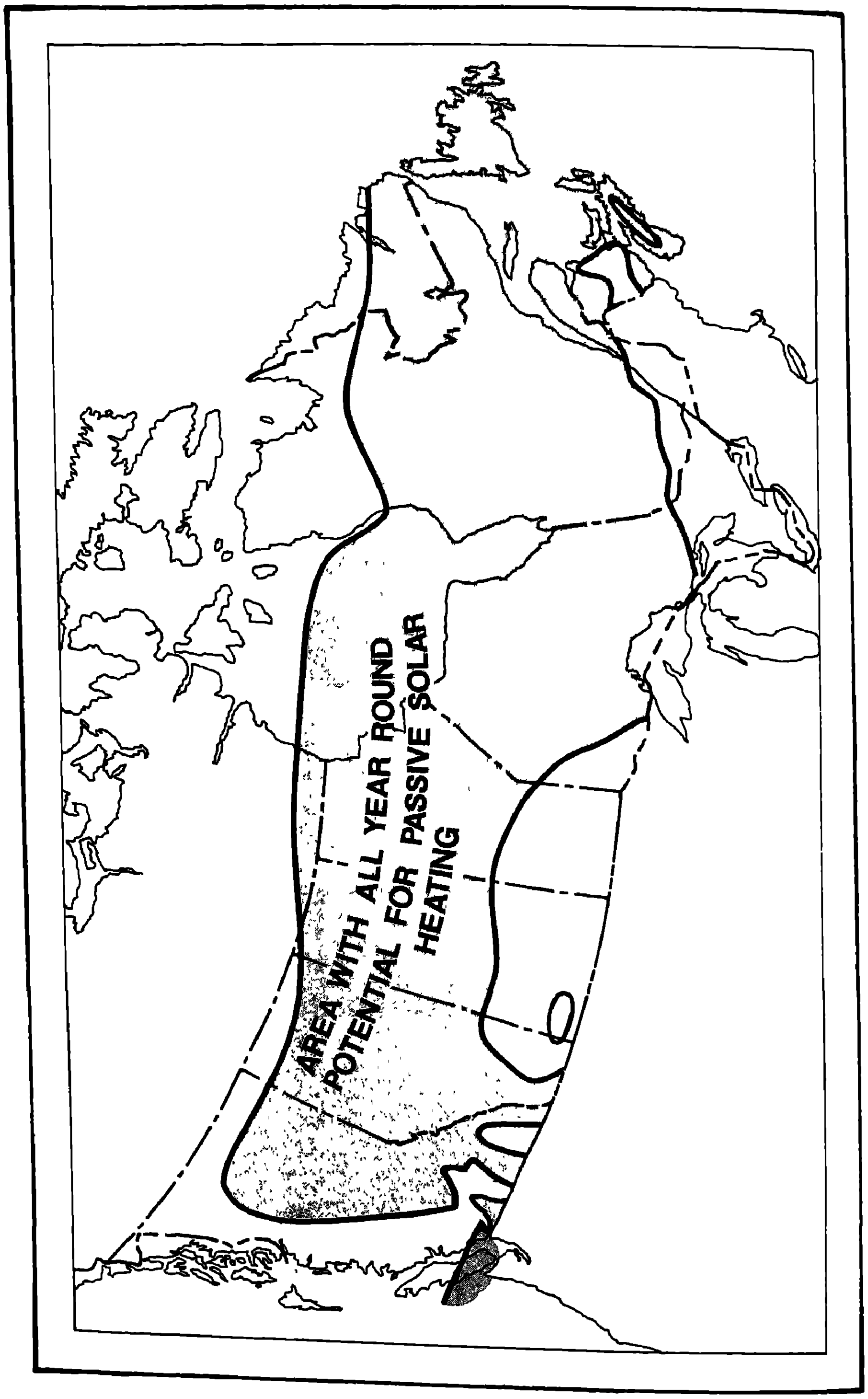


Figure 2 1.2 2-2

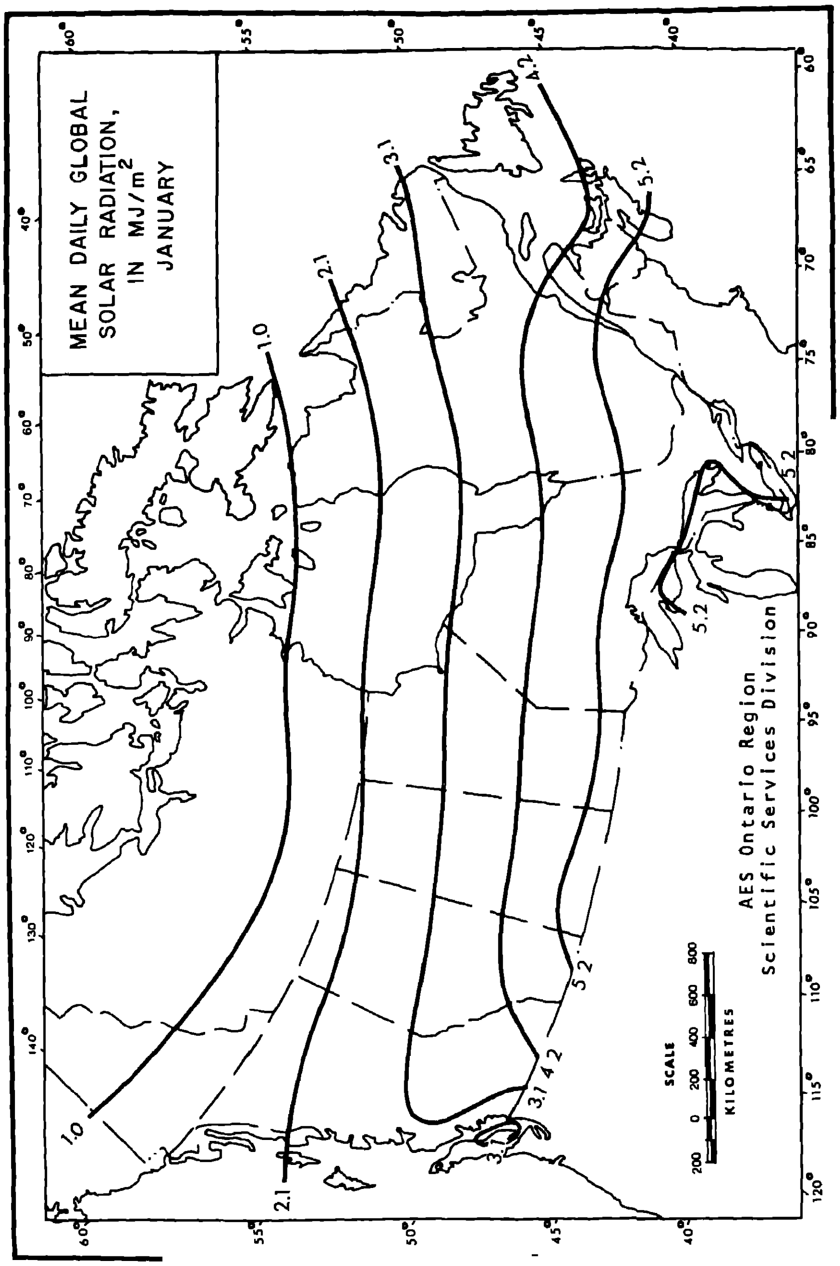


Figure 2 1.2.2-3

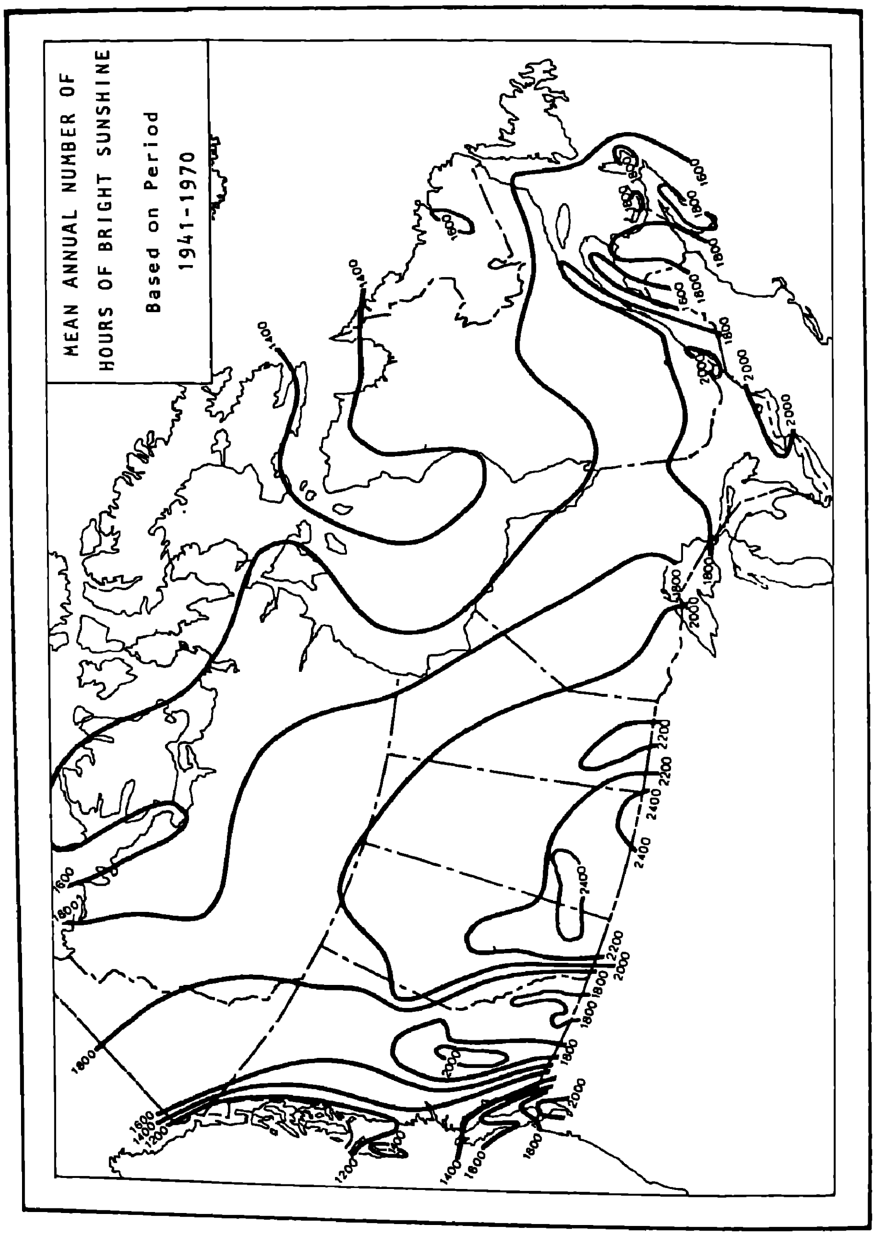


Figure 2.1.2 2-4

the demand at a given location or the contribution that passive solar heating can make to the total energy requirements, the following steps should be taken

—Multiply the amount of radiation falling on the horizontal surface by a factor which converts it to an amount falling on a vertical south-facing surface. The factors for each month at a number of Canadian locations are given in **Table 2.1.2.2-T$_1$**.

—Substitute this value into the following equation (which is based on a building that conforms to the assumptions in the example described above) [6]

$$\theta = 17.2°C - 0\,72 \times I_{south}$$

where I_{south} is the solar radiation in J/m^2 falling on a vertical south-facing wall.

—The value of θ gives the minimum mean daily temperature for which passive solar energy on an average day can meet all the heating requirements in a building of the assumed characteristics. It is also an indicator of the heat that would be available from passive solar heating on an average day

—If one modifies this computed value by accounting for building size and the area of glass on the south-facing wall, it is possible to assess the effectiveness of a number of passive solar energy designs

RADIATION DEFINITIONS	
Designation	**Name of Definition**
RF1	**Global Solar Radiation:** total incoming shortwave solar radiation from the whole dome of the sky received on a flat horizontally-mounted thermopile surface Instrumentation Eppley or Kipp pyranometer
RF2	**Sky Radiation (Diffuse)** that portion of the total incoming short-wave solar radiation from the whole dome of the sky received on a flat horizontally-mounted thermopile surface which is shielded from the direct rays of the sun by means of a shade ring Instrumentation Eppley or Kipp pyranometer with diffusograph (shade ring)
RF3	**Reflected Solar Radiation** that portion of the total incoming short-wave solar radiation from the whole dome of the sky which has been reflected from the Earth's surface on to a flat horizontally-mounted thermopile surface Instrumentation Eppley or Kipp pyranometer (inversely mounted)
RF4	**Net Radiation** the resultant of incoming and reflected short-wave radiation and outgoing long-wave radiation received through a flat horizontally-mounted thermopile Instrumentation CSIRO (Commonwealth Scientific and Industrial Research Organization) net pyrradiometer
RF7	**Natural Illumination·** the total of visible radiant energy (0 51 to 0 61 microns) from the whole dome of the sky received on a horizontally-mounted photovoltaic cell and measured in 1000 lm h/m^2 Instrumentation· Leeds and Northrup illuminometer

Table 2.1.2 2-T$_2$
Definitions of terms used in reference to radiation

SUMMARY OF DATA AVAILABLE FROM THE AES RADIATION NETWORK						
Station	Province	RF1	RF2	RF3	RF4	RF7
1 Alert	NWT	1964			1964	
2 Baker Lake	NWT	1970			1970	
3 Cambridge Bay	NWT	1971				
4 Coral Harbour A	NWT	1970				
5 Eureka	NWT	1970			1973	
6 Fort Smith A	NWT	1971				
7 Frobisher Bay A	NWT	1972			1972	
8 Hall Beach A	NWT	1970				
9 Inuvik UA	NWT	1973				
10 Isachsen	NWT	1970			1970	
11 Mould Bay A	NWT	1965			1968	
12 Norman Wells A	NWT	1967			1972	
13 Resolute A	NWT	1957	1957	1957	1963	
14 Sachs Harbour	NWT	1970				
15 Whitehorse A	Y T	1970				
16 Ocean Weather Stn P		1959			1967	
17 Cape St James	B C	1967				
18 Fort Nelson A	B C	1971				
19 Mt Kobau Obs	B C	1966				
20 Nanaimo Dep Bay	B C	1970				
21 Port Hardy A	B C	1967				
22 Prince George A	B C	1973				
23 Sandspit A	B C	1967				
24 Summerland Cda	B C	1955			1973	
25 Vancouver UBC	B C	1959				
26 Beaverlodge Cda	Alta	1960				
27 Edmonton Stony Plain	Alta	1966			1966	
28 Suffield A	Alta	1959				
29 Bad Lake	Sask	1971		1971	1971	
30 Swift Current Cda	Sask	1959				
31 Churchill A	Man	1964			1964	
32 The Pas A	Man	1972				
33 Winnipeg Int A	Man	1949				
34 Elora Research Stn	Ont	1970			1970	
35 Moosonee	Ont	1968			1968	
36 Ottawa NRC	Ont	1962			1962	
37 Toronto	Ont	1937				
38 Toronto Met Res Stn	Ont	1967	1967	1967	1967	1967
39 Trout Lake	Ont	1972				
40 Fort Chimo A	Que	1972				
41 Inoucdjouac	Que	1972			1972	
42 Montreal J Brebeuf	Que	1956	1964			
43 Nitchequon	Que	1973				
44 Normandin Cda	Que	1957				
45 Sept-Iles	Que	1973				
46 Fredericton Cda	N B	1960		1975	1975	
47 Halifax Citadel	N S	1964				
48 Kentville Cda	N S	1960			1972	
49 Sable Island	N S	1969			1969	
50 Charlottetown Cda	P E I	1971				
51 Goose UA	Nfld	1954	1962	1962	1962	
52 St John's West Cda	Nfld	1974				

RF1 = Global Solar Radiation
RF2 = Sky Radiation
RF3 = Reflected Solar Radiation.
RF4 = Net Radiation
RF7 = Daylight illumination

Table 2.1.2.2-T_3
Summary of data available from the AES network. The year refers to the year when radiation measurements began.

The Atmospheric Environment Service (AES) maintains an archive of radiation data collected from stations in its radiation network. Up to five radiation fields including global solar radiation, sky radiation (diffuse), reflected solar radiation, net radiation, and natural illumination (see **Table 2.1.2.2-T$_2$** for definitions) are reported for each station

Table 2.1.2.2-T$_3$ indicates the locations throughout Canada for which selected radiation measurements are taken, and the year when their records began Data in each of the relevant radiation fields are displayed in the following formats

—mean monthly total radiation for each hour
—mean monthly total daily radiation
—percentiles of hourly radiation
—means, extremes and standard deviation of daily radiation, and
—mean monthly percentage frequency of hourly radiation for each hour

Meteorologists frequently use hours of bright sunshine as a measure of the availability of solar radiation, ref **Figure 2.1.2.2-4** The annual total number of hours of bright sunshine normally is greatest over the Prairies ranging between 2000 and 2400 hours per year. It is less than 1400 hours over northwestern Quebec, parts of Newfoundland and locations along the coast of British Columbia For most places in Canada, July is the month with the greatest number of hours of bright sunshine and December the month with the least.

Hours of bright sunshine are also helpful in assessing the potential of passive solar heating. Some American specialists[8] use 60% of the daylight time as the threshold for encouraging the use of passive solar heating systems Since the number of hours of daylight for a year is 4384 hours, **Figure 2.1.2.2-4** indicates that, using these criteria[9], only restricted areas in southern Alberta and Saskatchewan should consider passive solar heating However, the prolonged heating season in Canada means that passive solar heating systems make a contribution to supplying heat for more months than in the United States Consequently, these systems can become cost-effective when the hours of bright sunshine are less than 60% of the daylight time.

2.1.2.3 Wind Direction and Speed

As outlined in **Section 2.1.1** winds are important because they influence the heating demand in the winter and has potential for natural ventilation in the summer During the winter, heating demands can be reduced by wind breaks (ref. **Section 4.9.3**) or by locating a building in an area of minimum wind speed In the summer, at southern latitudes, the requirements for air conditioning can be reduced by natural ventilation and this will be most effective if the building is situated in a location with relatively strong wind speeds In general, these normally occur near or over large bodies of water such as oceans, where there are no obstructions to the air flow, while the lowest wind speeds occur over rough terrain such as forests

The Atmospheric Environment Service takes wind measurements 10 m above ground for a large number of Canadian airports. **Figure 2.1.2.3-1** shows the distribution of mean annual wind speeds across Canada based on these data. Locations along the coast of British Columbia and Newfoundland have mean annual wind speeds greater than 32 km/h. For inland areas mean annual wind speeds greater than 24 km/h occur only over prairie provinces and in the Northwest Territories while several stations in the interior of British Columbia and the Yukon Territories have wind speeds less than 8 km/h. For Canada as a whole, the mean annual wind speed is near 16 km/h, with the lightest winds over the Yukon Territories and the strongest over the Maritime provinces. Wind speed maxima occur at different times during the year for different parts of the country. The strongest winds normally occur during the early winter in British Columbia and Newfoundland, during the late winter in the Maritimes and Quebec, during the late spring from the Rockies east through Ontario and during the early winter in the Territories. However, the precise periods of maximum and minimum wind speed will vary significantly from location to location as topography and built environment influence the wind field

Wind directions are even more difficult to categorize than wind speeds because they are affected by the large-scale circulation of the atmosphere and by local terrain features such as mountains, ridges, lakes, etc. **Table 2.1.2.3-T$_1$** lists the prevailing directions by season for a number of major Canadian locations In planning to minimize the heating demand by reducing the winds impacting on a building, one should ensure that wind breaks are erected upwind from it in the

PREVAILING WIND DIRECTION					
	Month				
Station	Year	D,J,F	M,A,M	J,J,A	S,O,N
Vancouver Int l A	E	E	E	E	E
Edmonton Int l A	S	S	SE	WNW	S
Calgary Int l A	NNW	W	NNW	NNW	W
Regina A	SE	SE	SE	SE	SE
Winnipeg Int l A	S	S	S	S	S
Thunder Bay A	W	W	E	E	W
Windsor A	SW	SW	SSW	SW	SSW
London A	W	W	E	SSW	W
Toronto Int l A	N/W	N	N	N	W
Whitehorse A	SE	SSE	SE	SE	SE
Ottawa Int l A	WNW	WNW	WNW	SW	E
Montreal Int l A	WSW	WSW	WSW	SW	WSW
Quebec A	WSW	WSW	ENE	SW	WSW
Fredericton A	SSW/WNW	WNW	WNW	SSW	WNW
Charlottetown	W	W	N	WSW	W
Halifax Int l A	S/SSW	WNW	SSW	SSW	NW
St John's A (Nfld)	WSW	W	WSW	WSW	W
Whitehorse A	SE	SSE	SE	SE	SE

Table 2.1.2.3-T$_1$
Prevailing wind directions for major canadian cities (1955-1972) by year and by **season.**

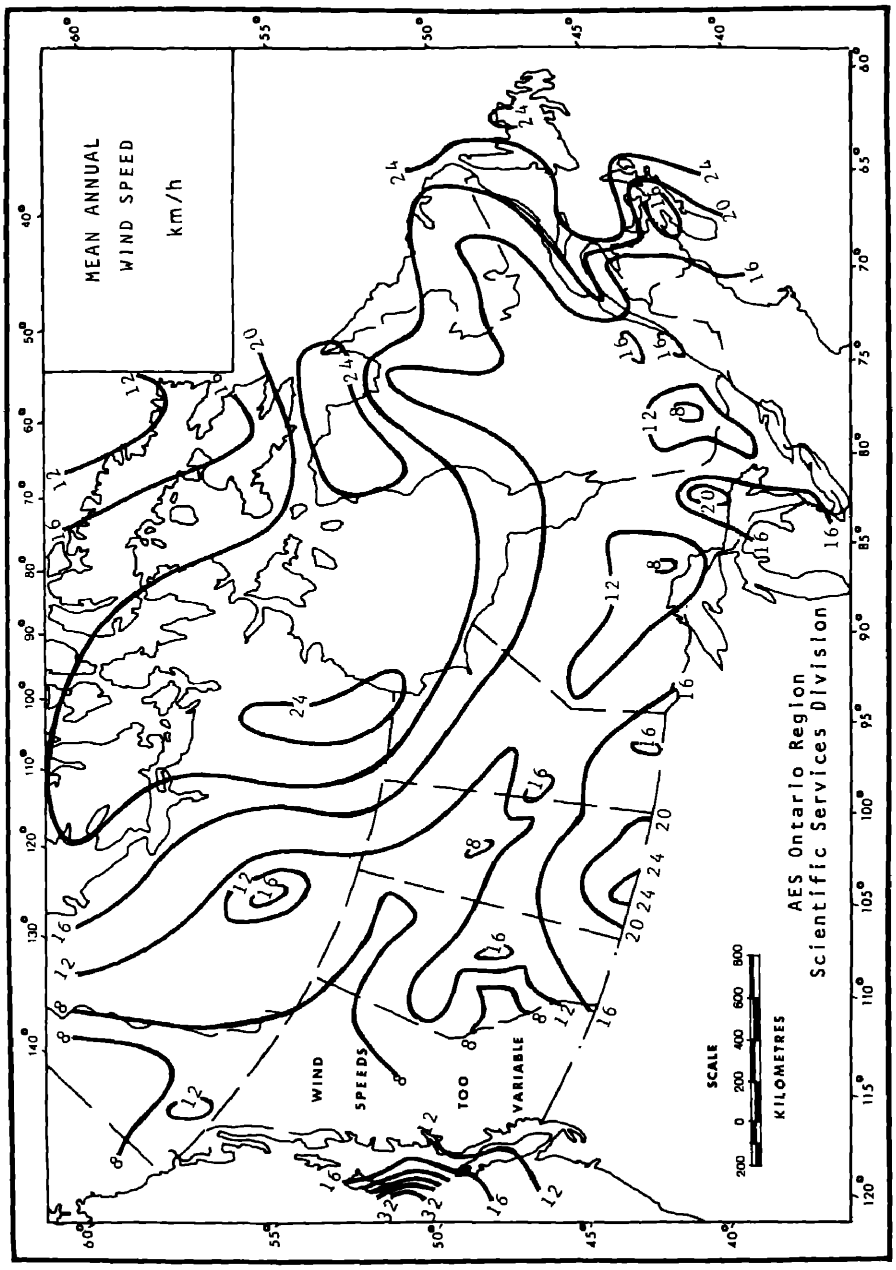


Figure 2.1 2.3-1

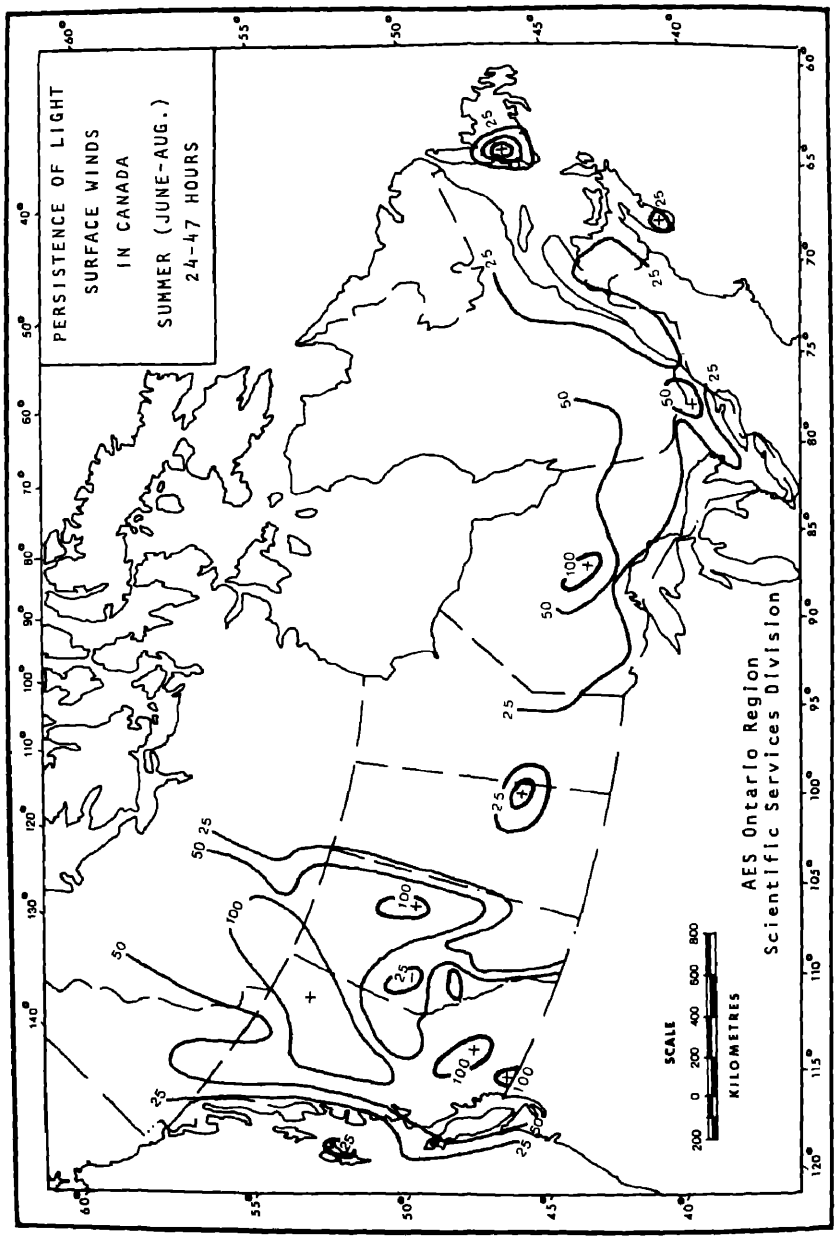


Figure 2.1.2.3-2[10]

direction of the prevailing wind during the winter. On the other hand, if one is trying to enhance natural ventilation, then the large openings in dwellings or other types of building should be placed on the side where the prevailing summer winds come from (Ref **Section 3.9.2**)

In planning natural ventilation systems or aerogenerator systems, it is important to assess the reliability of the wind Shaw et al[11] have presented maps showing the frequency of persistent light surface winds based on 10 years of record **Figure 2.1.2.3-2** shows the frequency of occasions when wind speeds at 10 m were less than or equal to 11 km/h for periods of 24 to 47 hours during the period from June to August inclusive According to this map, prolonged periods of light winds occur most frequently in northern and central B C , in northwestern Alberta, and in Ontario north of Lake Superior Although the patterns change some from season to season, these areas tend to experience more prolonged periods of light wind speeds than any other parts of Canada in every season **Figure 2.1 2.3-2** suggests that natural ventilation would be less effective in B C and northern Ontario Fortunately, with the exception of parts of southern B C , the light winds occur in areàs where the cooling demand is small

2.1.2.4 Precipitation

Precipitation is another meteorological parameter that should be considered in energy conservation programs in Canada, particularly in the winter The distribution of precipitation provides an indication of areas where the climate is moist and where frequent cloud may minimize the effectiveness of passive solar heating systems

Snow is also an important consideration in energy conservation In areas with low mean wind speeds and a heavey snow cover that lasts throughout the winter, buildings can obtain useful insulation from snow which can be banked against their lower walls The build-up of substantial snow loads on roofs can be similarly beneficial

Figure 2.1.2.4-1 shows the distribution of mean annual precipitation amounts The map indicates that precipitation amounts vary with latitude The smallest amounts of precipitation occur in the Arctic and the largest along the southwest and southeast coasts In southern Canada, the smallest amounts of precipitation occur over the Prairie Provinces and in isolated locations in the interior of British Columbia

The greatest seasonal variation in precipitation amount is recorded along the British Columbia coast and in the coastal valleys where the wet season begins late in September and ends about mid-March, considerable variation also occurs over the Prairies where the heaviest precipitation occurs in conjunction with convective storms during the summer months

The median depths of snow at the time of maximum snow cover are shown in **Figure 2.1.2.4-2.** According to this map the deepest snow covers are measured in the Rocky Mountains and on Vancouver Island, where, in local areas, the depths exceed 320 cm. The maximum snow depths are smallest along the ocean coasts, in the Prairie Provinces, in southwestern Ontario and in the high Arctic.

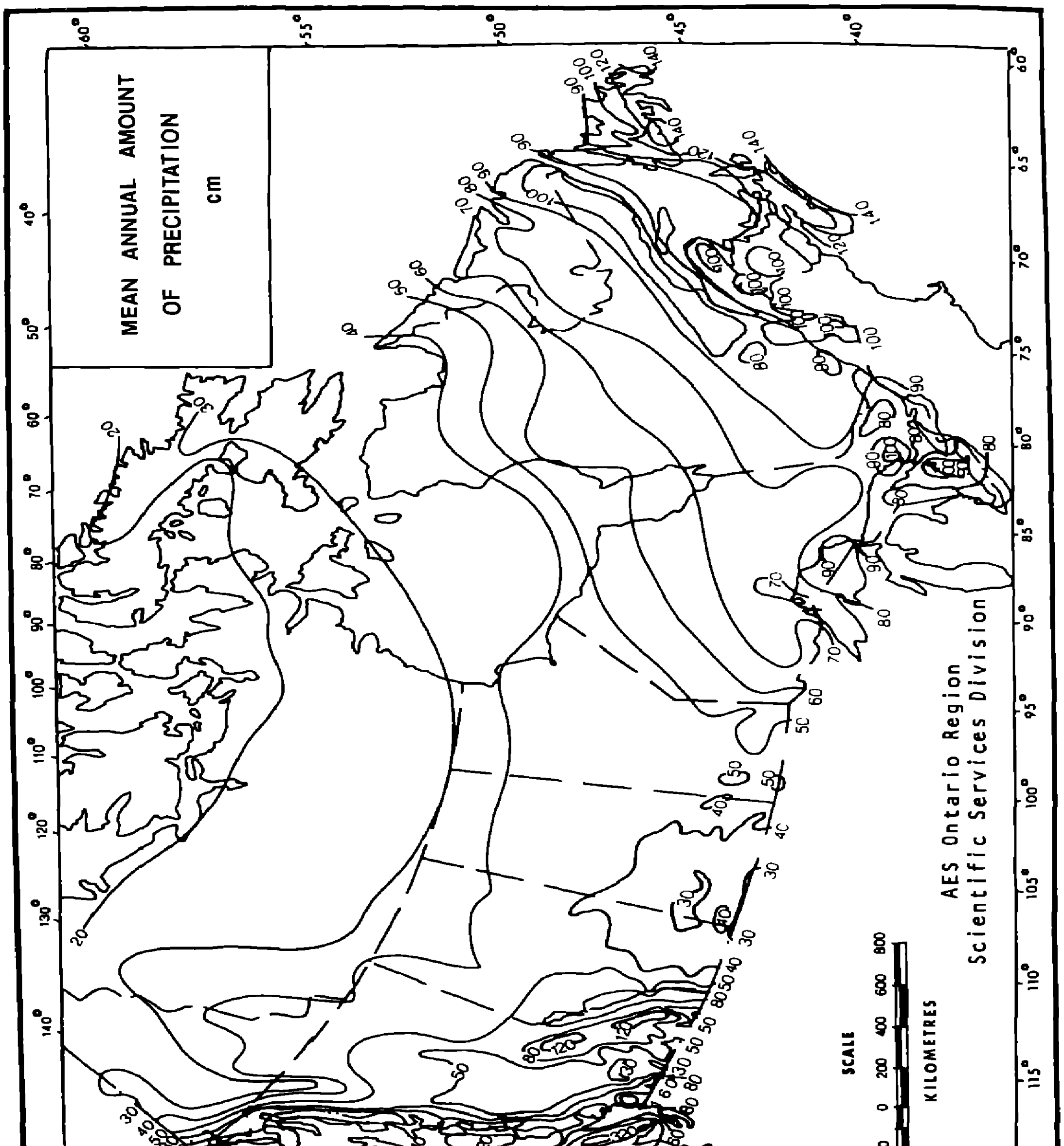


Figure 2.1 2.4-1

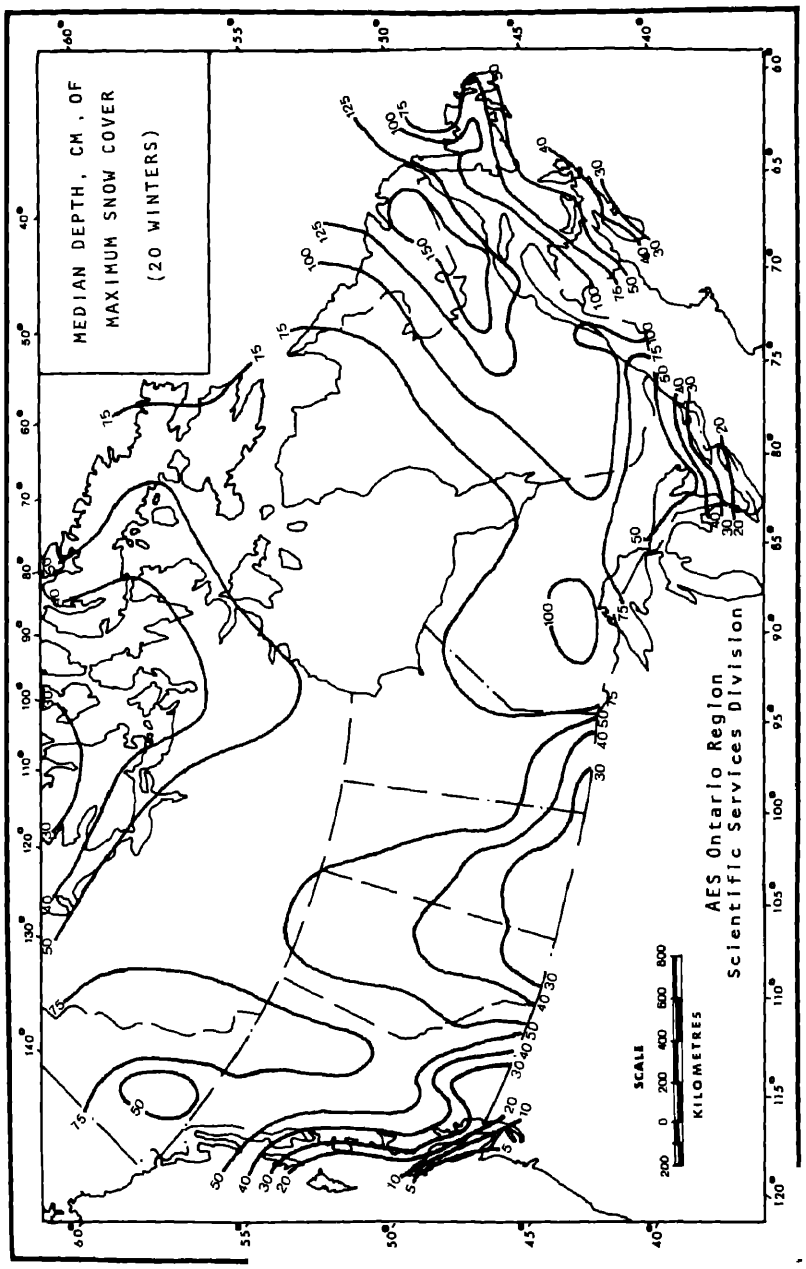


Figure 2.1.2.4-2[12]

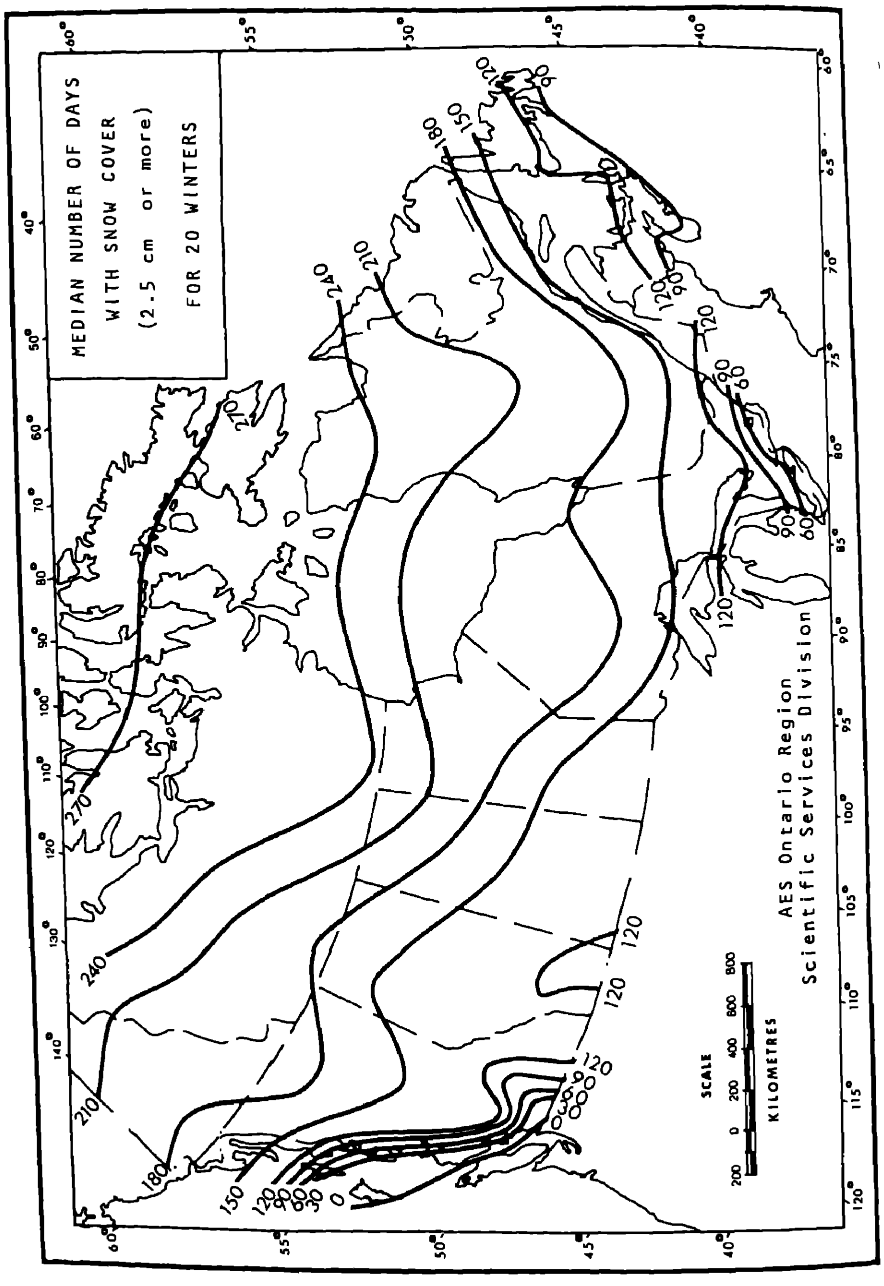


Figure 2.1 2 4-3

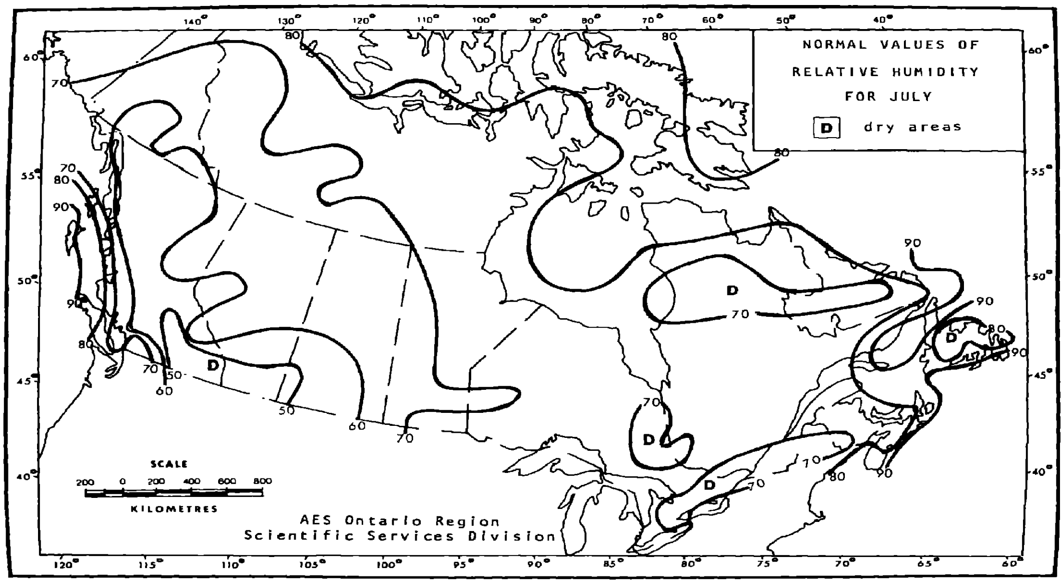
The importance of snow cover for an energy conservation strategy will also depend on its duration and reliability **Figure 2.1.2.4-3** shows the distribution of the median number of days with 2.5 cm of snow cover or more. According to this map the snow cover lasts for 3 months or less on the West Coast and in south-western Ontario It also lasts less than 120 days in the Maritimes and southern Alberta during the median year In the Arctic, at all locations, the snow cover is very persistent lasting at least 170 days

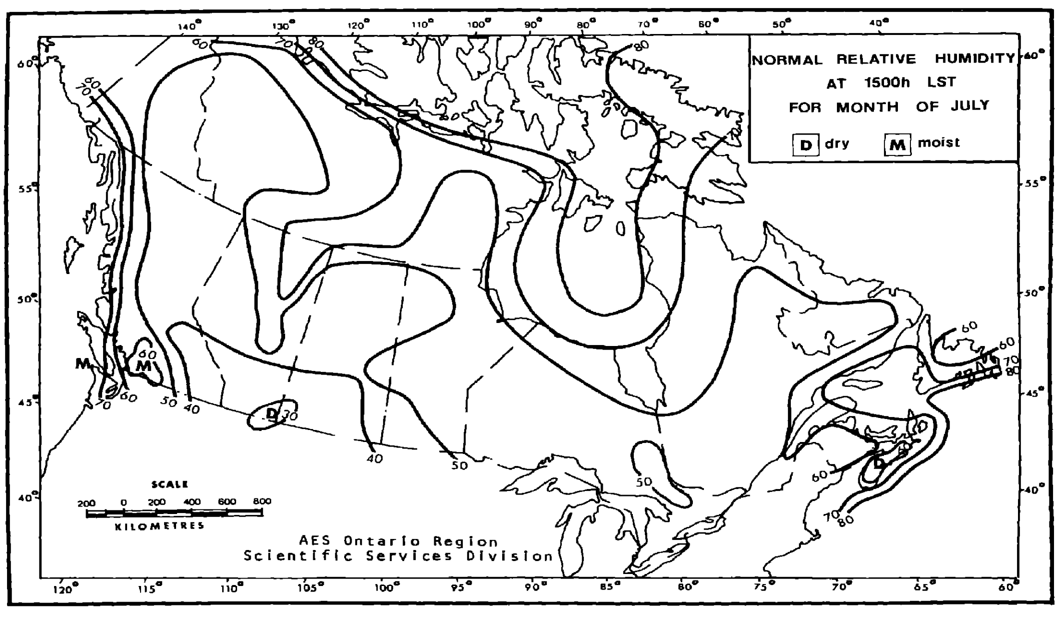
However, the snow in the Arctic is usually not helpful as insulation for buildings because the snowfalls are generally light and the fine, dry snow which does fall is rapidly blown off roofs and away from buildings by the strong winds The reliability of the snow cover from year to year is also important With the exception of southern Alberta, where the snow cover may exceed 2 5 cm for less than 30 days during some winters, the cover can be considered reliable for all locations north of 48°N

2.1.2.5 Moisture in the Atmosphere

The evaporation of water into the atmosphere from fountains, ponds, artificial lakes, etc can have a cooling effect in localities where the air is naturally dry The potential for evaporative cooling decreases as the ambient relative humidity increases **Figure 2.1.2.5-1** was developed to show the average daily relative humidity during July for different parts of Canada According to this map, the mean relative humidities across Canada during the month of July normally vary from a high over 90% on the eastern and western coasts to a low of less than 50% in southeastern B C and southern Alberta It should be noted that cool air with a specific amount of moisture per unit volume will have a higher relative humidity than warm air with the same amount of moisture Based on the distribution of relative humidities it would appear that the potential for evaporative cooling is largest in valleys within southern B C and areas of southern Ontario

Relative humidities undergo large diurnal variations Consequently, the value of relative humidity near the time of maximum temperature is a better indicator of the potential for evaporative cooling than the average daily relative humidity **Figure 2.1.2.5-2** shows the distribution of relative humidity values at 1500 LST The pattern on this map is similar to the pattern in **Figure 2.1.2.4-3** with minimum values occurring in the southern parts of the Prairie provinces and maximum values occurring near the oceans However, as would be expected, the values are less than the daily averages. Over large areas of southern Alberta and Saskatchewan, the relative humidities are less than 40% In these areas there would be a large potential for using ponds, water fountains, etc. to reduce the temperatures in the vicinity of buildings This energy conservation strategy would be particularly effective for buildings in major urban centres in this area


NORMAL VALUES OF
RELATIVE HUMIDITY
FOR JULY
D dry areas
SCALE
KILOMETRES
AES Ontario Region
Scientific Services Division


NORMAL RELATIVE HUMIDITY
AT 1500h LST
FOR MONTH OF JULY
D dry M moist
SCALE
KILOMETRES
AES Ontario Region
Scientific Services Division

2.1.2.6
Site Specific Climatological Analysis

The graphs presented in this section illustrate the types of climatological analysis that can be carried out for specific locations. These analyses provide more detail on the yearly, monthly and diurnal variations in the demands for heating and cooling and in the potential of the environment to assist in energy conserving building design Similar analyses can be completed for any major centre by the Atmospheric Environment Service on a cost-recoverable basis. In order to discuss the possibility of having a particular Canadian site analyzed, the reader should consult with one of the offices listed in **Table 2.1.2.1-T$_1$**.

.1 **Heating Demand**: The heating demand as a function of month and hour can be assessed in several ways. One method is to analyze the mean temperature on this basis The analysis can result in a graph similar to that shown in **Figure 2.1.2.6-1**. When temperatures are below 18°C there is a demand for heating and when they are above some critical threshold (such as 24°C) there is a demand for cooling. **Figure 2.1.2.6-1** indicates that the demand for heating in Toronto is greatest during the night time hours and during the month of January

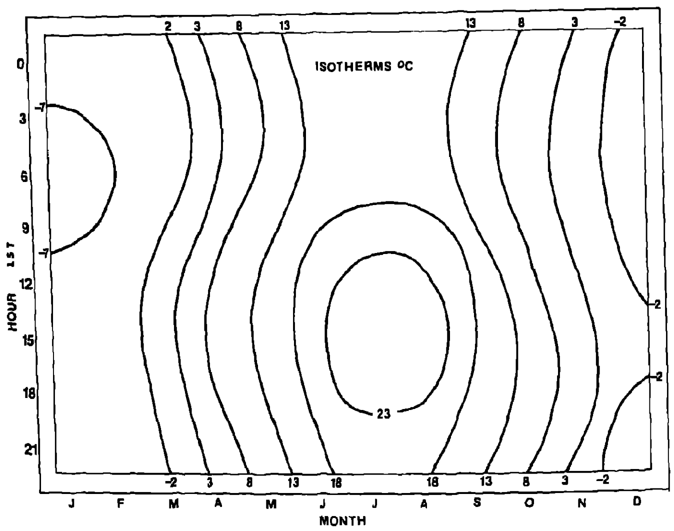


Figure 2.1 2.6-1
Mean temperatures by hour and month for the Toronto International Airport

However, on any given day there are two factors which may influence this First, winds. If the winds are very strong during a certain part of the day, then the heat loss will be greatest during that period even though the temperatures may not be at their daily minimum. Second, increased solar radiation during the day The incoming solar radiation can create passive solar heating and reduce the heating demand during daylight hours.

It is possible to do further analysis of the frequency of days with large heating demand during a heating season **Figure 2.1.2.6-2** shows the average total number of days with heating degree-day values greater than selected values for Toronto for the period from

1959 to 1972 inclusive. As outlined in the following paragraphs, this information can be combined with the relationship between heating degree-day values and heating demand to estimate the maximum demand that has been experienced in Toronto during any past heating season

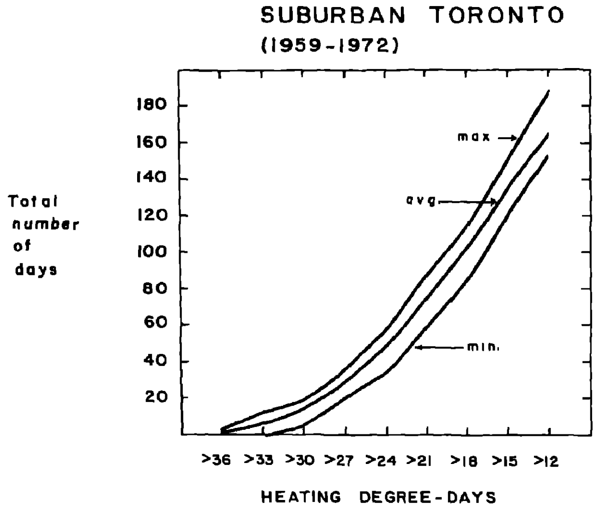


Figure 2 1 2 6-2
Average total number of days with HDD values greater than selected values for Toronto, 1959-1972 inclusive

The heat loss of a dwelling is inversely proportional to the *RSI* value of the building material and insulation, and directly proportional to the outside surface area and the difference between inside and outside temperatures The value of the heat loss coefficient and the area of the space heating load is determined by multiplying the building's thermal insulation and its surface area However, this value does not account for internal heat gains such as passive solar heating nor heat loss due to varying air infiltration or exfiltration.

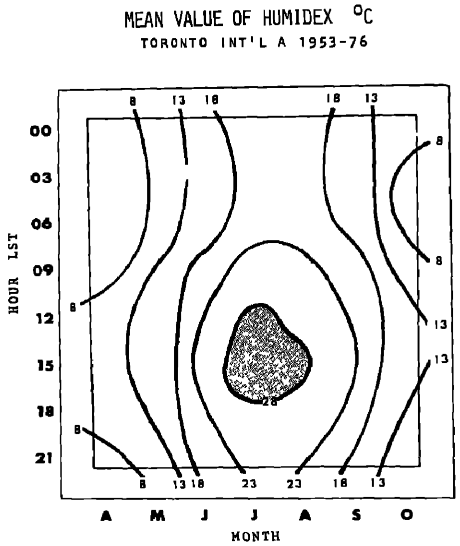
Heat losses from two bungalows with the same gross liveable area of 100 m² but with different design and different heat loss coefficients could be as high as 26.98 or as low as 13.44 MJ/°C/d. **Table 2.1.2.6-T_1** shows the heating demand of two houses with these UA values for different degree-day values.

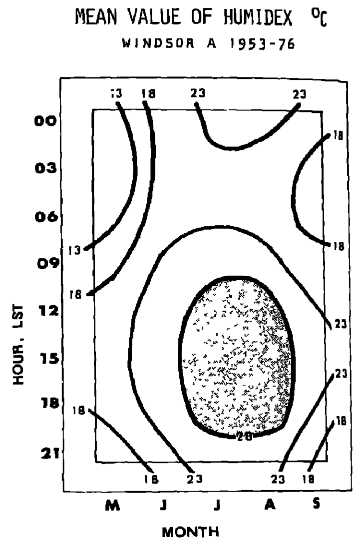
U Value	Heat Loss, MJ/°C/d								
	HDD 36	HDD 33	HDD 30	HDD 27	HDD 24	HDD 21	HDD 18	HDD 15	HDD 12
13 44	484	443	403	363	323	282	242	202	161
26 98	971	890	809	728	648	567	486	405	324

Table 2 1 2.6-T_1
Variations in heating demand associated with variations in heating degree-days [13]

2.1 External Spaces and Climate

In order to ensure an adequate supply of heat at all times, it will be necessary to base system designs on periods of unusually high demand rather than average value statistics **Figure 2.1.2.6-3** provides climatological statistics that can be used in assessing the extreme heating demand in Toronto Similar graphs are available for a number of other Ontario locations[14] Also available from the same source are graphs showing the variability of solar radiation in Toronto and Ottawa and the frequency of occasions when the heating demand is large and the average solar radiation is small





2.1 2 6-3a

2 1 2 6-3b

Diurnal variation in humidex at Toronto and Windsor

FREQUENCY DISTRIBUTION OF WINDS 1953-1972														
Wind Direction	Total Number of Hours	Speed Category, km/h									Percent	Mean	Speed Limit	Above Limit
		1-3	4-6	7-12	13-17	18-23	24-29	30-35	36-40	41-46				
Calm	7 882	—	—	—	—	—	—	—	—	—	4 50	—	—	--
NNE	5 709	0 39	0 01	1 29	0 44	0 12	0 01	—	—	—	3 26	8 2	46	-
NE	5 194	0 42	0 99	1 15	0 33	0 08	0 01	0 00	—	—	2 96	7 7	46	--
ENE	4 436	0 19	0 59	1 10	0 47	0 16	0 01	0 00	—	—	2 53	9 6	46	-
East	7 515	0 35	0 79	1 73	0 89	0 39	0 12	0 01	0 00	—	4 29	10 6	46	-
ESE	5 170	0 20	0 65	1 37	0 54	0 17	0 02	0 00	0 00	—	2 95	9 7	46	--
SE	7 752	0 41	1 33	2 26	0 39	0 03	0 00	—	—	—	4 42	7 9	46	--
SSE	7 796	0 39	1 30	2 24	0 45	0 06	0 00	0 00	—	—	4 45	8 1	46	—
South	10 552	0 78	1 99	2 52	0 57	0 14	0 02	0 00	—	—	6 02	7 7	46	--
SSW	8 307	0 40	1 14	1 93	0 81	0 35	0 08	0 02	0 00	0 00	4 74	9 8	46	—
SW	13 648	0 55	1 50	2 93	1 53	0 85	0 29	0 09	0 02	0 01	7 78	11 3	46	0 01
WSW	12 885	0 43	1 18	2 56	1 59	1 03	0 38	0 12	0 04	0 01	7 35	12 4	46	0 00
West	18 364	0 88	2 16	3 36	2 00	1 36	0 53	0 15	0 02	0 01	10 47	11 6	46	0 00
WNW	12 633	0 47	1 28	2 25	1 60	1 12	0 38	0 10	0 01	0 00	7 21	12 3	46	0 00
NW	12 632	0 70	1 80	2 38	1 25	0 77	0 23	0 06	0 00	0 00	7 21	10 4	46	—
NNW	15 497	0 59	1 93	3 35	1 79	0 91	0 23	0 03	0 00	0 00	8 84	10 7	46	0 00
North	19 348	1 07	2 95	4 55	1 76	0.61	0 08	0 01	0 00	—	11 04	9.1	—	—
Total	175 320	8 22	22 59	36 98	16.42	8.16	2.39	0 60	0 11	0 03	100 00	9 7	—	0 01

Table 2.1.2 6-T_2
Frequency distribution of winds categorized by direction speed for the Toronto international airport.[15]

.2 **Cooling Demand**: Although the requirements for air conditioning are frequently assessed by the use of cooling degree-days, humidex values provide a more comprehensive measure since they are based on both temperature and humidity The diurnal variations in humidex at Toronto and Windsor during the summer months are shown in **Figures 2.1.2.6-3a** and **2.1.2.6-3b** respectively According to **Figure 2.1.2.6-3a,** the humidex values are largest in Toronto during the month of July If we accept 28°C as the threshold for the use of air conditioning then, on the average, use of air conditioning will occur between 1100 and 1700 LST in July and between 1400 and 1600 LST in August In Windsor the period for which air conditioning is required would be longer, stretching from 0930 to 2000 LST in July and from 1030 to 1900 LST in August

In many buildings the maximum demand for cooling occurs even later in the day because it takes some time for many buildings to absorb the heat After these buildings become heated it takes additional time for them to cool Consequently, the requirements for air conditioning may be shifted to later time periods than indicated by **Figures 2.1.2.6-3a** and **2.1.2.6-3b**.

.3 **Wind Characteristics**: Another type of analysis that has been carried out for all major Canadian airports shows the frequency distributions of winds by year and month **Table 2.1.2.6-T_2** provides an example of the annual frequency distribution for the Toronto International Airport Tables of this nature are useful in determining the best location in orientation for wind breaks (when one uses winter wind distributions) and for determining the side of the building where openings for natural ventilation should be constructed (using summer frequency distribution analysis) They can be obtained from the Airport Handbook[16]

.4 **Solar Radiation Data**: Solar radiation data are available from several sources If one is concerned about the average daily global solar radiation falling on horizontal surfaces as well as surfaces with varying elevations reference should be made to Hay's report[17] On the other hand, readers wishing to acquire values of global solar radiation by hour and day on a regular monthly basis can do so by subscribing to Monthly Radiation Summaries[18] published by the Atmospheric Environment Service

2.1.3 Climatic Variability and the Changing Atmospheric Composition

Climatologists rely on a number of methods to establish the trends in climate Since direct meteorological measurements have been available for less than one hundred years at most Canadian locations, any long-term study of climatic variations must be based on proxy data derived from tree ring analysis, lake core analysis, carbon 14 dating, etc Canadian climatologists have attempted to infer the climatic conditions that prevailed in earlier centuries. Their findings suggest that, neglecting increased anthropogenic inputs of CO_2 and heat.

> 'the interglacial warmth of the past 8,000 years or so will eventually change to a colder, more glacial regime. The onset of that change may be a number of millenia or centuries away, conceivably it may already have begun. It seems likely that this transition will be sufficiently gradual so that in the next 100 to 200 years it would be almost imperceptible amid the ubiquitous variability of climate. There is however a very small yet definite

probability that a much more rapid cooling of climate will occur in the same time period'[19]

The climate also exhibits short-term variations For example, there is increasing evidence to indicate that the climate during the 1970's is different from that of the 1950's and 1960's In particular, the years of 1972, 1973, 1974, the fall of 1976, and the winter of 1976/77 have been unusual In 1972 the mean annual temperatures were below normal across Canada, ranging from 3 8°C lower in northern Quebec to 1 1°C below normal on the east and west coasts The unusually cold year of 1972 was followed by an unusually warm year in 1973 Then came 1974, another cold year in all parts of Canada with the exception of British Columbia These relatively large year-to-year variations have continued into the last part of the decade

Short-term climatic trends have been documented by running means. **Figure 2.1.3-1a** shows the centred 10-year running means of annual average temperatures at Toronto According to this graph, the mean annual temperature was close to 6 7°C prior to 1890 After that date the annual averages increased to a maximum to 9 2°C by 1950 Part of the increase must be attributed to the increasing heat island effect which accompanied the growth of Toronto

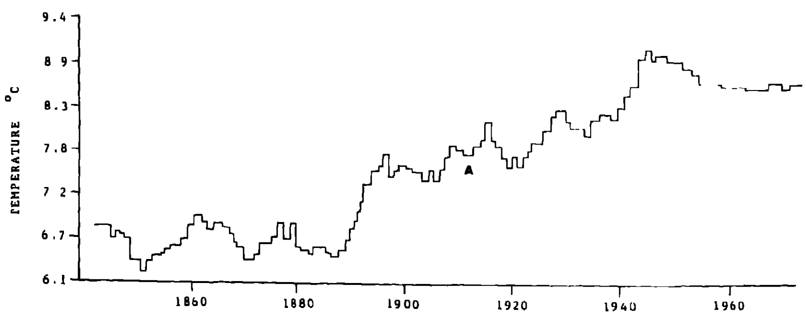


Figure 2 1 3-1a
Average annual temperatures at Toronto

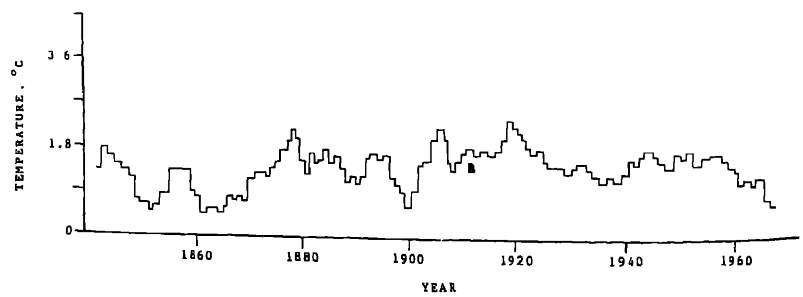


Figure 2 1.3-1b
Five year running means of year to year variations in annual mean temperatures at Toronto [20, 21]

The trend of the mean variations in annual temperature over periods of five consecutive years in Toronto is shown in **Figure 2.1.3-1b.** This graph shows the variations ranged from 0.3°C to 2.3°C. The largest changes occurred in the 1870's, 1900's and 1910's while the smallest were recorded in the 1860's, 1930's and 1960's.

These results indicate that we are entering a period when yearly and seasonal average temperatures and precipitation amounts will differ from normal by amounts greater than those observed in the 1950's and 1960's Consequently, when making a detailed assessment of heating demand for long periods, caution should be exercised in using only normals for the 1941-1970 period.

Figure 2.1.3-2 shows the variation in the number of days when the HDD values exceeded certain thresholds for heating seasons in Toronto According to this graph there are large fluctuations in the number of days when the HDD values exceed thresholds of 18 and 21 On occasion, year-to-year variations for both thresholds exceeded 20 days per heating season. Similarly, HDD values exceeding 33 may never occur in a mild heating season but they may be recorded on as many as 16 days in a cold one.

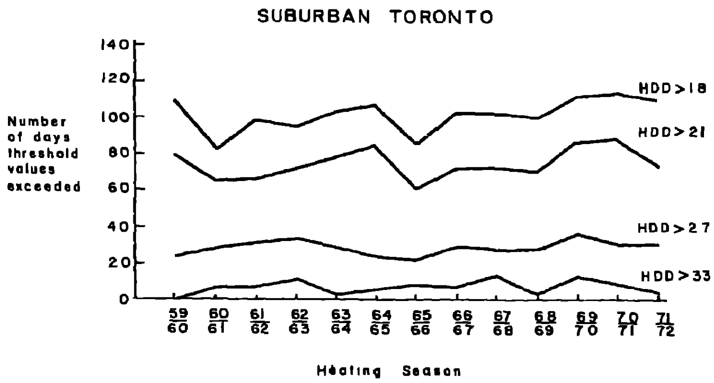


Figure 2 1.3-2

Variations in the number of days when HDDs exceed certain thresholds for heating season in Toronto [22]

Climatic fluctuations can also result from variations in the composition of earth's atmosphere. The increasing use of fossil fuels to heat homes and to generate electricity is resulting in the emission of large quantities of CO_2 into the atmosphere. **Figure 2.1.3-3** shows the consequences of this practice at Mauna Loa, an observatory in Hawaii which is considered to be far removed from sources of CO_2.

According to the projections presented by Schneider[23], CO_2 concentrations will reach nearly 390/10^6 by the year 2000 Increased CO_2 concentrations will increase the ability of the atmosphere to absorb the infrared radiation emitted by the earth, thereby causing the air to warm (this is commonly referred to as the greenhouse effect). By the year 2000, this effect will likely have produced a net global warming of 1°C.

Particulate emissions from industry must also be considered. Particulates have the effect of reducing the direct beam solar radia-

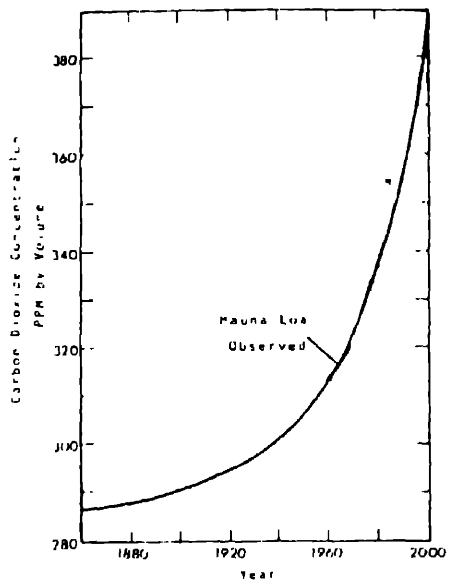


Figure 2.1.3-3
Past and projected trends in CO_2 concentrations Mauna Loa Observatory, Hawaii [24]

tion received at the surface and increasing the frequency of cloud and fog. Consequently, it can be concluded that, all other factors being equal, Canada's industrialization could result in a slight decrease in the potential for active and passive solar heating.

2.1.4 Topoclimatic Influences Upon Energy-conserving Architecture

Throughout the world during the past several decades, abundant and relatively inexpensive energy supply have encouraged the design of buildings and cities without thought to the type of climate in which they are located. The climatic sensitivity of buildings was rarely considered, rather, technological methods were used to maintain conditions of comfort. The problem of overheating in buildings in temperate climates has been further aggravated by the tendency toward taller buildings with larger glass surfaces

With the more recent trend towards less abundant and more expensive energy supplies, architects and planners have attempted to design more efficient buildings based on principles of energy conservation[25, 26, 27]. To this end an understanding of the relationships between topography and climatology can be of considerable value.

Two of the primary objectives in designing Canadian buildings to conserve energy are:
—to reduce to a minimum energy loss during winter, and
—to reduce to a minimum energy gain during summer, while still maintaining adequate temperature, ventilation, and relative humidity characteristics, both physical and psychological, necessary to human comfort Topographical variations can influence energy loss and gain through their influence on meso- and microclimatic conditions.

Table 2.1.4-T_1 indicates general relationships between topographical characteristics and selected meteorological variables. Only very general relationships are indicated and often these are extremely variable, depending on the time of year, location within Canada, and magnitude[28, 29]. For example, the effects of elevation will vary considerably between the Dundalk Upland in southwestern Ontario, and the Rocky Mountains, on the west coast[30]. These limitations must be taken into consideration when general 'rules of thumb' are abstracted from Table 2.1.4-T_1 and applied to a specific location

2.1.4.1 Elevation

Elevation influences all of the meteorological variables listed in Table 2.1.4-T_1. Generally speaking, temperature decreases as altitude increases while the actual temperature and the rate of decrease depend on the air mass and time of year. Heating degree-days therefore increase with elevation. Absolute and relative humidities are often more dependent on factors other than elevation, and have less significance for building design.

Mean wind speeds tend to increase with height[31, 32, 33, 34]. Wind frequency tables, maximum speeds, and computed and recorded gusts are available for many stations throughout Canda from the Atmospheric Environment Service[35, 36, 37] In mountainous areas at high altitudes where vegetation becomes very sparse, in-coming short-wave radiation is not intercepted as it is at sea level by vegetation and physical features, and so tends to increase Averaged over a year, radiation at high elevations on cloudy days can increase as much as 30-35% because diffuse radiation is intensified by the comparatively thin layer of cloud Total precipitation tends to increase with height, and a greater percentage falls as snow, rather than rain

2.1.4.2 Slopes

Slopes influence wind speeds and directions and indirectly, temperatures Upslope (anabatic) and downslope (katabatic) winds can influence temperatures, and inversions (warm air aloft) can result in heating degree-days being greater in valleys or at the base of slopes than on upper parts[38] Cold air drainage down slopes, especially at night and in autumn, winter, and spring, can create pockets of cold air and frost hollows. The angle of the slope and the elevation of the sun will determine the amount of solar radiation at the surface

Slope and aspect often exert their influences together North-, south-, east-, and west-facing slopes all experience unique microclimates, which can often be detected in variations of vegetation. For example, north-facing slopes receive much less direct solar radiation than do south-facing slopes and are often cooler and have greater soil moisture[39, 40].

2.1.4.3 Albedos

Table 2.1.4.3-T_1 provides the average albedos of a variety of natural surfaces Albedo is a measure of the ratio of reflected radiation to total incoming radiation A fresh snowfall, for example, creates a brilliant white surface which reflects more than 75% of the incoming solar radiation. Colour, material and texture are significant.

TOPOGRAPHICAL INFLUENCES ON CLIMATOLOGICAL VARIABLES

	Minimum Temperature	Maximum Temperature	Heating Degree-Days	Humidity	Wind Speed and Direction	Cloud Cover	Radiation	Rainfall	Snowfall & Snow Cover
Elevation	Inverse relationship	Inverse relationship	Increase with height	Fog moisture available to plants at greater heights	Increase speed with heights	Increases with elevation Fog also increases with height	Increases with height Outgoing rad remains same	Rain increases with height Proportion of rain of total precipitation decreases	Snowfall increases with height Wetness of snow decreases with height
Slope	Cold air drainage can be directed Direct relationship with speed of cold air drainage	Max temp highest at bottom of slope in summer Variable location in winter	Higher in valley than in thermal belt on above slope	No direct influence	Angle influences the speed of movement of cold air at night Anabatic and katabatic flow	Increased with slope angle	Increases or decreases radiation, depending on slope angle	Windward and leeward slopes will be wet and dry (rain shadows) respectively	Windward and leeward effects on snowfall
Aspect	Aspect less important at night as temperature controlled by flow of cold air	West slopes higher than east slopes South slopes higher than north slopes Valleys running N-S & south-facing slopes have highest max	North-facing aspect will have higher HDD than south-facing aspect	Absolute humidity not affected Relative humidity is affected	Will depend on direction slope is facing and wind direction e g windward or leeward	Extremely variable depending upon time of year air mass etc	Will be most on south-facing & least on north-facing	Windward or leeward—either increase or decrease in rainfall	Windward or leeward—either increase or decrease in snowfall Snow cover greatest in NE slopes
Albedo	Can increase or decrease min temperature considerably	Can increase or decrease max temperature considerably	Can increase or decrease HDD	Can increase or decrease evaporation & influence humidity	Can create pockets of ascending & descending air	Convective clouds predominate in the afternoon Layer clouds predominate after sunrise	Influences percentage of radiation absorbed	No direct influence	Can influence snow cover e g localized melting

TOPOGRAPHICAL INFLUENCES ON CLIMATOLOGICAL VARIABLES									
	Minimum Temperature	Maximum Temperature	Heating Degree-Days	Humidity	Wind Speed and Direction	Cloud Cover	Radiation	Rainfall	Snowfall & Snow Cover
Nature of Surface	Higher with grass than with bare soil Lowest with bare rock	Lower with grass than with bare soil Highest with bare rock	Compaction of soil or surface can influence heating degree days	Short grass evaporation greatest after rain Water surface evaporation greatest on bright days & on days of drought	Roughness coefficient determines eddies & local currents	Low albedos can create convective clouds	High albedos reflect much radiation Low albedos absorb short-wave & emit long-wave	No influence on rainfall but considerable on evaporation, percolation, runoff, etc	No influence on snowfall but considerable influence on snow cover distribution
Water Bodies	Modified by nearness to water bodies Is a function of water temp, and sizes	Modified by nearness to water Is a function of water temp and size of water body	Decreases with nearness to water bodies	Increased humidity	Usually increased by travelling over water	Extremely dependent upon time of year	Can reflect light upwards onto slopes	Often increased near shore as winds pick up moisture, pass over cold land Air condenses and precipitates	Often increased near shore as winds pick up moisture, pass over cold land Air condenses and precipitates
Vegetation	Increase in min temp with increase in veg	Decrease in max temp with increase in veg	Within the vegetation canopy HDD are reduced The taller the vegetation, the greater the influence	Increases humidity through evapotrans-piration Depends on density of growth	Decreased wind speed within the vegetation canopy	No influence	Total incoming and outgoing radiation remains same but varies within the vegetation canopy	Rainfall not influenced but evaporation, drainage, etc are changed by vegetation	Snowfall not influenced but snow cover distribution and snow melt are
Hills and Valleys	Frost follows & lower minimums Thermal band on slopes above valley inversion	Max temp above valley on slope in winter Max temp on valley floor rest of year	Higher in valley than on slopes except at great heights	Can trap moist air in valleys	Passive effects greater as wind speed increases Less wind in valleys except storms funnelled by valleys Ventilation factor	Cause increased cloudiness due to long-wave rad, decreased temp	Can exclude early morning late afternoon radiation	Windward and leeward slopes wet & dry respectively	Snowfall increased on upper slopes except where swept by winds

Table 2.1.4-T_1
Topographical influences on climatological variables

Heating demand, therefore, can be increased or decreased slightly for individual buildings depending upon the albedo of the topography and exterior surfaces of the building Ceilings under a grey roof, for example, may be as much as 6°C warmer than those under a whitewashed roof.

ALBEDO OF VARIOUS SURFACES	
Surface	**Albedo, %**
Fresh snow cover	75-95
Dense cloud cover	60-90
Old snow cover	40-70
Clean firm snow	50-65
Light sand dunes, surf	30-60
Clean glacier ice	30-46
Dirty firm snow	20-50
Dirty glacier ice	20-30
Sandy soil	15-40
Meadows and fields	12-30
Densely built-up areas	15-25
Woods	5-20
Dark cultivated soil	7-10
Water surfaces, sea	3-10

Table 2 1 4.3-T_1
Albedo of various surfaces for total solar radiation, with diffuse reflection [41]

Table 2.1.4.3-T_2 indicates the effect of albedo on interior wall temperatures. The importance of albedo in architectural design is discussed in several sections of this handbook The reader is referred particularly to a discussion of the emissivity of building materials in section 3 6 1 and to the consideration of design criteria for new construction which will be found in section 4.0.

2.1.4.4 Nature of Surface and Subsurface

The nature of the surface (e g concrete vs grass) has a direct bearing on the absorption and reflection of incoming radiation, the emission of long-wave radiation and, consequently, on temperature and heating degree-days, the interception of rainfall, and the distribution of the snow cover

Soil type has a significance for underground buildings or portions thereof Tight clay soils, i.e. those that are highly impervious, require expensive water removal and waterproofing systems The ideal type of soil for building is one which is highly permeable, permitting water to drain away rapidly. Soil temperature is also important. Aston[42] records mean soil temperatures at depths of 10, 50, 100, 200, 500, 1000, 1500 and 3000 mm in the early morning and late afternoon for 47 locations throughout Canada, based on the period 1958-1972

Also, Figure 2.1.4.4-1 illustrates relationships between wind-speed, air temperature and soil temperature as recorded in 1953 by Lettau and Davidson[43]. It can be seen in the illustration that (a) wind speed increases with height above the ground, (b) during the day the air temperature is highest just above the ground, (c) during the summer, soil temperatures decrease with depth, and

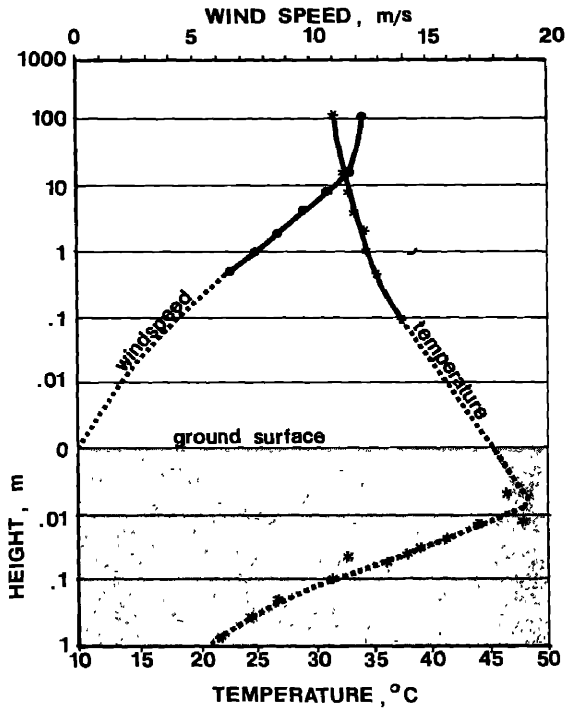


Figure 2 1 4 4-1
Relationship of windspeed, air temperature and soil temperature [44]

(d) soil temperatures are highest in a very thin layer at the surface, often being well above the simultaneous air temperature. When water is available, evaporation tends to be much higher over impervious man-made surfaces (e.g. roads and sidewalks) than over vegetated surfaces where rainfall percolates through the soil Vegetation acts as a barrier to wind[45] Wind speeds at the base of corn stalks are much reduced from those above the canopy The snow cover distribution may also be considerably modified by the presence of vegetation and buildings.

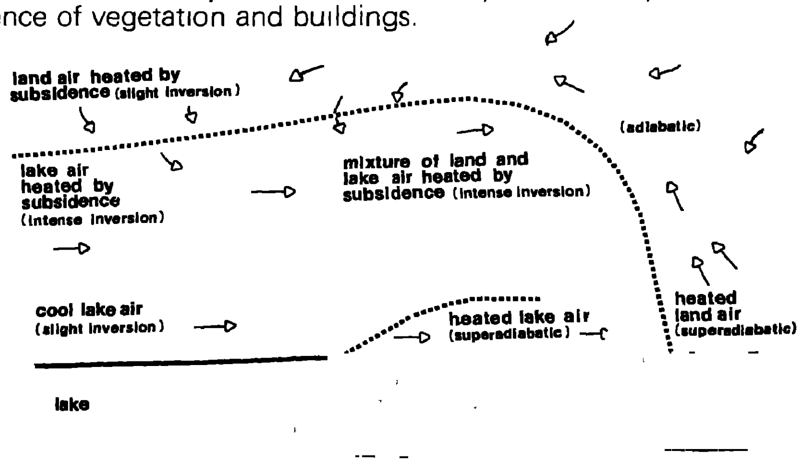


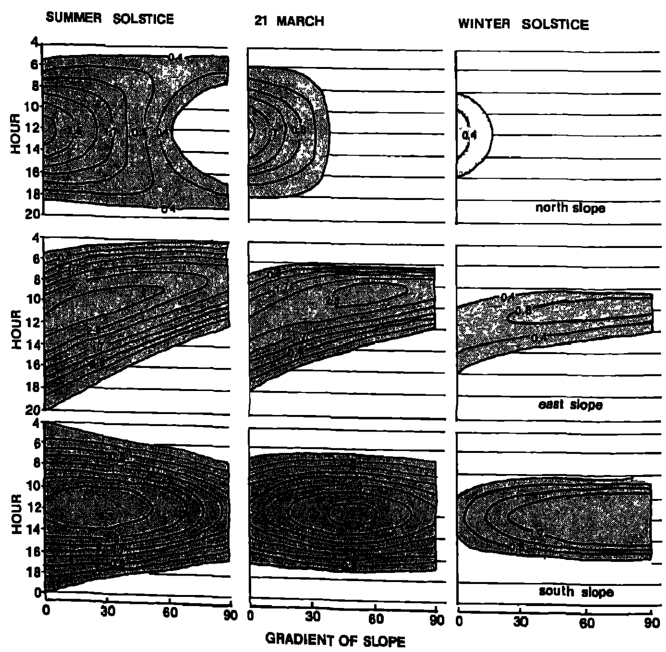
Figure 2.1.4.5-1
Sea breezes.[46]

2.1.4.5 Water Bodies

The influence of water bodies on meteorological variables is well known in southern Ontario where lake-effect snow storms and cool onshore breezes, **Figure 2.1.4.5-1**, occur adjacent to the Great Lakes. The size and temperature of the water body, and the time of year, are also important. On average, temperatures are modified near the water, with lower maximum, and higher minimum temperatures occurring near the shore rather than at inland locations. The influence of water bodies on winds, depends upon the time of day. In summer weather they tend to be onshore in the afternoon as the rising air from the warm land mass is replaced, breezes moving in from the cooler water body. The winds tend to be offshore at night when the water becomes warmer than the land

2.1.4.6 Aspect

The influence of aspect upon radiation is illustrated in **Figures 2.1.4.6-1** and **2.1.4.6-2**. The former displays variations in solar radiation for slopes of 0° to 90° for northern, eastern, and southern aspects at the time of the summer and winter solstices and spring equinox The fact that south-facing walls receive much more direct solar radiation than do north-facing walls is of major significance to exterior and interior design in buildings Heat stress in summer, for example, and comfortable warmth in winter will extend from the southern wall inward In residences, passive, relaxing activities should be enjoyed in the southern portions of the house Work areas should be adjacent to the northern wall **Figure 2.1.4.6-2** illustrates mean daily shortwave radiation against a vertical wall during January and July at Toronto Values for other Canadian cities can be abstracted from Hay.



2.1.4.6-1
Influence of aspect on radiation.[47]

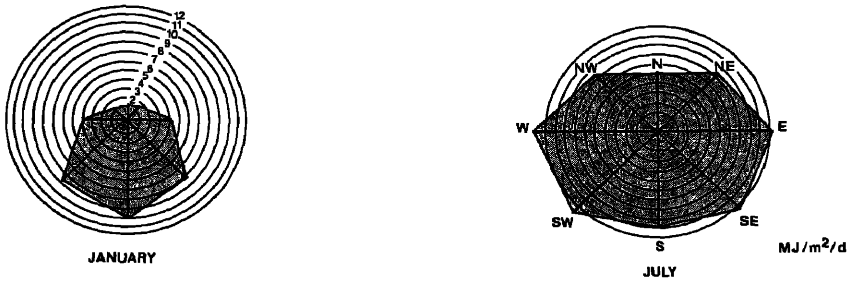


Figure 2.1.4 6-2
Mean daily January and July values of daily shortwave radiation on a vertical surface, Toronto [48]

2.1.4.7 Hills and Valleys

Under 'hills and valleys', **Table 2.1.4-T$_1$** lists some conditions likely to prevail in the more topographically variable regions of the country such as the Rocky Mountains. Meteorological conditions tend to be much more site-specific, with temperature and wind variables, especially, being very dependent on local conditions **Figure 2.1.4.7-1** illustrates daily relationships between slope and valley winds

Air pollution and risk-of-frost problems in a valley are related to the ventilation (or lack of it) The ventilation in such locations can be defined as 'good' or 'poor' using the following formula:

$$D = \frac{d}{d+b} \times \frac{d}{t}$$

where d = width of valley measured from ridge to ridge
b = width of valley at the bottom, and
t = depth of valley

The greater the magnitude of 'D' the better the ventilation

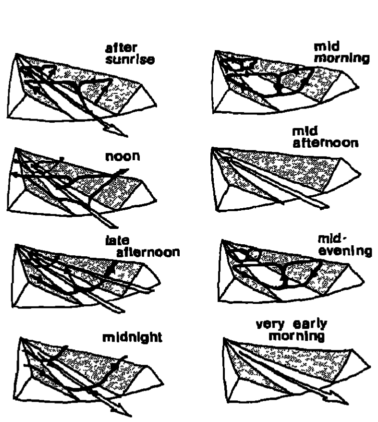


Figure 2.1.4.7-1
Slope and valley winds.[49]

Ventilation also depends on the direction of the prevailing wind, so that the quantities of 'd' and 'b' must be measured in this direction. By comparing the magnitude of 'D' on maps of ventilation, it is possible to identify those areas which, comparatively speaking, are well or poorly ventilated.

2.1.4.8 Topoclimatic Elements of Design

Each of the topoclimatic relationships outlined in **Table 2.1.4-T_1** may be used to encourage energy conservation in building location, orientation, design and component material[50, 51, 52, 53, 54].

The total radiation load on any structure is optimal (e g most heat in winter, least in summer) with the long walls running in an east-west direction[55, 56, 57, 58, 59] Most heat loss from a building will tend to occur through north-facing walls, doors and windows because the north wall receives the least amount of direct solar radiation and is exposed to cold north-westerly winds These factors should be taken into consideration by minimizing window and door space in the north-facing wall. Conversely, south-facing walls should maximize window area, properly protected against heat loss and summer heat gain, to maximize winter solar-heating The use of overhangs, the projection of which will depend on solar position which in turn is dependent on latitude, shade trees, screens, or blinds will minimize heat gain during the summer months. (Ref. **Section 4.9** Protective Elements). Overhangs, in addition to shading southern walls, also protect them from rain and snow.

Illumination is important, both physically and psychologically, inside any building[60] Diffuse (sky) radiation is more often preferred to direct solar radiation because of the heating capabilities of the latter. Clerestories can be effectively used to increase illumination without increasing heat gain.

Buildings located on top of a hill will experience windier conditions than those at lower elevations[61, 62] Building walls must be thick enough to withstand rain penetration during periods of high wind speeds Also, guttering should be large enough to handle the precipitation from an average heavy storm Wind speed may be reduced or enhanced (for ventilation purposes) through the careful location of buildings adjacent to each other Air flow is also influenced by the pitch of the roof These particular variables are especially significant on slopes and in valleys where local climatological conditions are dependent on specific topography.

Vegetation can significantly alter microclimates For example, coniferous trees, located on the north and west sides of a building will reduce the speed (and therefore cooling power) of the wind This is of greatest significance during the winter months. In southern latitudes, deciduous trees growing on the south side of the building will provide shade during summer (thereby reducing heat gain) ref **Table 2.1.4.8-T_1**, and during winter will lose their foliage and permit the sun to shine directly on the building (encouraging heat maintenance).

Vegetation may also be strategically located to shelter buildings from a cold air flow or to channel a cool summer breeze Shrubs located parallel to a wall at a slight distance from it will shield the building from rainfall penetration. If the shrubs are too close they will tend to hold moisture against the wall, possibly resulting in

damp spots. Willow and fig trees will help to transpire excessive soil moisture into the air The presence of too many trees and shrubs, however, will result in pools of stagnant air, with little or no ventilation

SHADING EFFECTIVENESS	
Coefficient of Shading Effectiveness	**Shading Object**
0	Clear window
9	Inside dark roller, half drawn
19	Inside dark roller, drawn, inside medium roller half drawn
25	Inside dark blind drawn
29	Inside light roller, half drawn
34	6 mm heat absorbing glass, inside medium blind, drawn
38	Inside medium roller, drawn
42	Dark grey heavy drapes
45	Inside white blind, drawn
40-50	Tree performing light shade
53	Light grey heavy drapes
57	Outside awning, two-thirds drawn
60	Inside white roller drawn, off-white heavy drapes
72	Outside aluminum shading screen
75	Outside canvas awning (dark or medium)
75-80	Dense tree providing heavy shade
85	Outside white awning, drawn

Table 2 1 4 8-T_1
Shading effectiveness of various objects[6,1]

2.1.4.9 Summary

Ideally, buildings should be located where topography and vegetation provide the most suitable microclimate Building orientation should both take advantage of and compensate for solar radiation and wind Groups of buildings can be designed so that individual microclimatic characteristics of wind, radiation, temperature, and precipitation interact in a positive manner Finally, building materials should be chosen for their ability to perform their required functions In addition to resisting wind pressure and precipitation, they should permit exchanges of air and moisture with the surroundings admitting and intercepting daylight and solar heat at appropriate times of the day and year. By using topoclimatic relationships to design passive solar energy systems for individual buildings and entire communities, significant advances can be made towards energy conservation.

2.1.5 Urban Climates

As Canada's population increases and more people become concentrated in urban centres, the modifications to climate resulting from urbanization intensify. The large surface areas of pavement and concrete, the presence of tall buildings located in close proximity, the emissions of heat from domestic heating and industrial activities and the concentrations of sources of air pollution all contribute to the uniqueness of the urban climate. The modified meteorological fields in a city influence energy consumption in both the summer and winter. In the winter the warmer temperatures in the city reduce

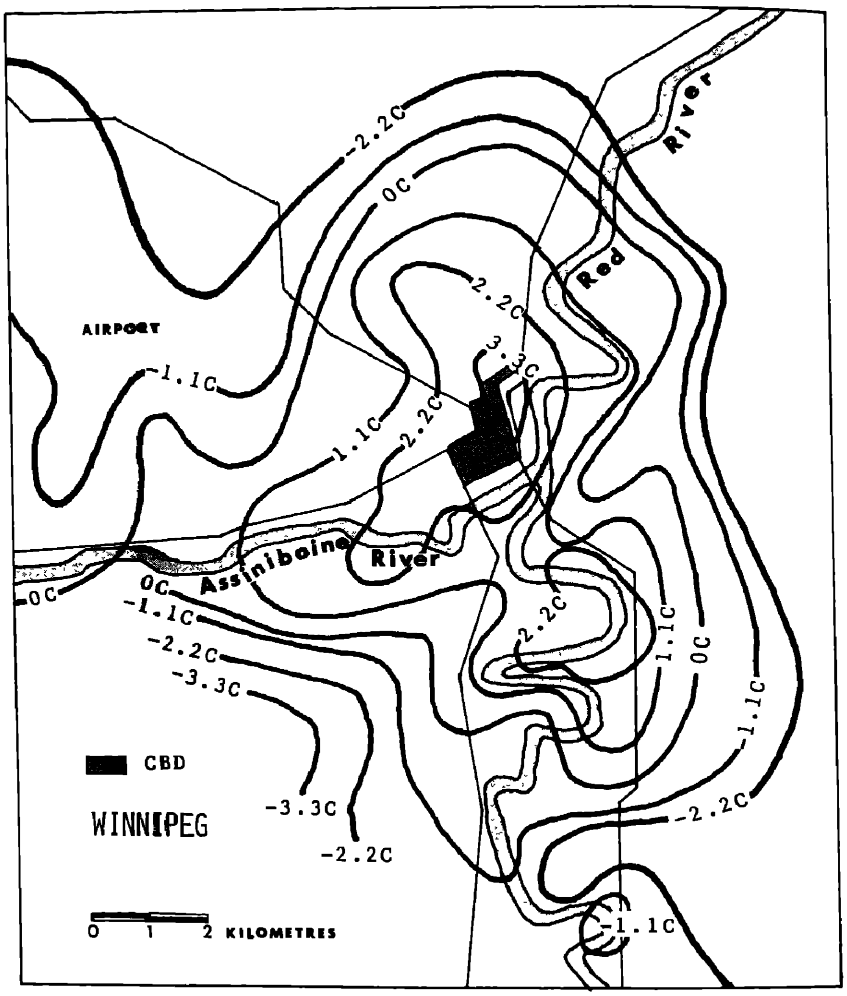


Figure 2.1.5.1-1$_a$

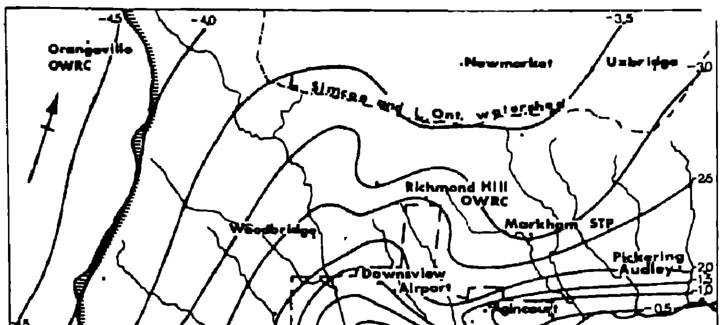


Figure 2.1.5.1-1$_b$
Temperature deviations associated with heat island in Winnipeg and Toronto.[64 65]

the heating demand. On the other hand, they increase the cooling demand in the summer In addition, the modified climatic conditions can change the effectiveness of some standard energy conservation techniques.

2.1.5.1 The Urban Heat Island

The asphalt, stone and concrete surfaces in a city absorb and store heat much better than vegetation or soil During the day these dark surfaces absorb the sun's radiation Then during the evening and the night they slowly release this heat In addition, the buildings generally tend to reduce the air flow in the city and thereby reduce the advectional cooling.

In most major Canadian centres the urban/rural temperature difference associated with the heat island is largest on winter days under clear sky conditions The heat island is usually smaller and on occasion may be barely detectable during the daylight hours in the summer and early autumn

Frequently the urban heat island is a maximum in areas of dense population and high industrialization and then falls away gradually in the suburban areas until the temperatures become the same as those in completely rural environments **Figures** 2.1.5.1-1**a** and 2.1.5.1-1**b** show the areal extent of the temperature deviations associated with the heat islands in Winnipeg and Toronto respectively The map for Winnipeg represents the urban effects alone, while the map of Toronto shows the effect of the urban heat island for a city adjacent to a large lake

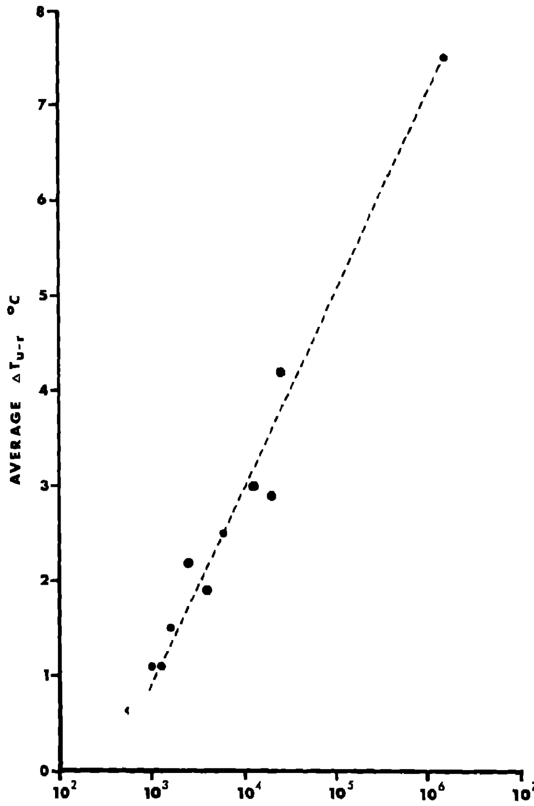


Figure 2.1.5.1-2
Relationship between average urban/rural temperature difference and population.[66]

URBAN-RURAL DECADAL MEAN TEMPERATURE DIFFERENCE			
City	January	July	Annual Average Reduction in HDD's
Montreal	4 9°C	3 6°C	513
Ottawa	2 9°C	1 7°C	298
Toronto	5 2°C	3 5°C	801
Winnipeg	2 3°C	1 2°C	428
Calgary	2 3°C	2 3°C	387
Edmonton	2 6°C	3 3°C	466
Vancouver	2 6°C	4 1°C	445

Table 2 1.5.1-T_1
Summary of the decadal mean differences between temperatures in the city centre and the rural environs, at the time of minimum temperatures

A review of data from climatological stations in major urban centres by Crowe[67] for the 1961-70 period indicated that the heat island effect is largest in Montreal and Toronto, the two most populated cities in Canada. **Table 2.1.5.1-T_1** summarizes the maximum temperature differences for 7 major Canadian cities The urban heat island can also make large changes in heat consumption through the heating season. As shown in **Table 2.1.5.1-T_1**, the difference in the number of accumulated heating degree-days between the urban and the rural environments is 801 in Toronto and 513 in Montreal. Oke has developed a graph to indicate the relationship between the average urban/rural temperature difference and population. This graph is shown in **Figure 2.1.5.1-2**.

2.1.5.2 Winds in the City

Buildings in cities increase the surface drag on the wind. As air encounters these irregularities, the low level wind speeds are reduced and the turbulence in the flow is increased

For a given stability, surface wind speeds are generally less in the city than in the country. Buildings of varying shapes and sizes crowded together in compact city cores can be very effective in blocking the winds Estimates of the effects such as that shown in **Figure 2.1.5.2-1** indicate that at 200m the wind speed increases to 95% of the geostrophic value (wind speed which occurs when there are no frictional effects) in the country and it is only 68% of the geostrophic value in the city

The information in **Figure 2.1.5.2-1** can be a useful guide in determining the best height for an aerogenerator in a suburban or urban environment For a given wind speed and aerogenerator type, the same outputs would be produced by an aerogenerator at 50 m in a rural area as one at 275 m in the city or one at 155 m in a suburban area.

The spacing of buildings is a critical factor in determining the amount of obstruction that will occur. If the buildings are packed very closely together in-city flows will be greatly reduced. As a result, the heat island effect will be increased. Although this effect reduces the energy demand in the winter and transforms some of the snow to rain, it causes problems in hot, humid periods in the summer and during air pollution episodes. On those occasions, the hot, humid air or the polluted air are not flushed from the city centre as rapidly.

It has been reported that, for strong winds, the in-city speeds will be 10% less than the airport winds. On the other hand, the in-city speeds will be 40% less than the airport winds for light wind conditions The effects of urbanization on winds can be reduced by building structures of varying heights separated by wide thoroughfares or open spaces.[68]

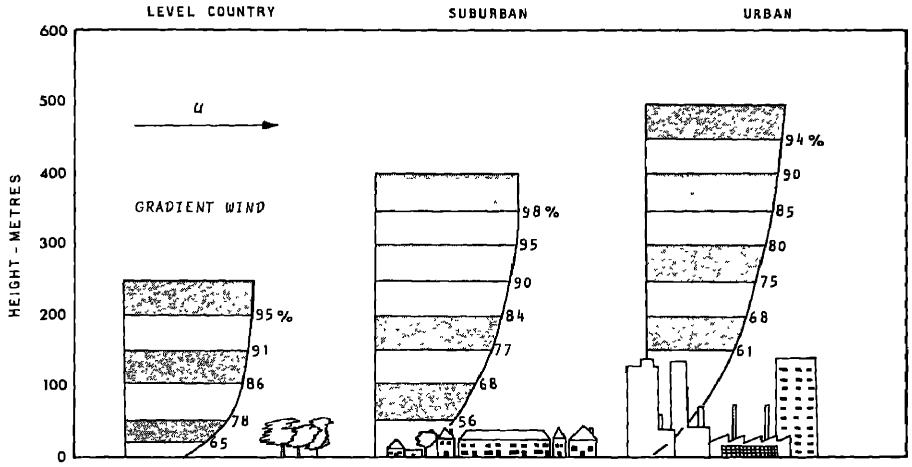


Figure 2.1.5.2-1
Percentage of wind speed over rural, suburban and urban terrain [69]

Cities also produce increases in the frequency and intensity of turbulent eddies in the lowest levels of the atmosphere Some of these eddies are very structured due to the interactions of the wind with specific building configurations The effects of buildings have been studied in wind tunnels The results of these studies indicate that buildings deflect the winds upwards, downward and laterally. As winds are deflected downward, they transport their higher velocities down from the upper levels resulting in localized wind maxima at the surface where the surface winds are 2 to 3 times as strong as the mean wind speed These effects are amplified by the presence of streets lined with tall buildings The street

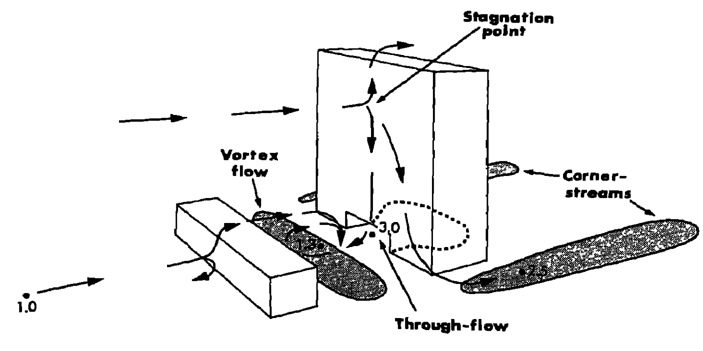


Figure 2.1.5.2-2
Effects of an individual building on air flow.[70]

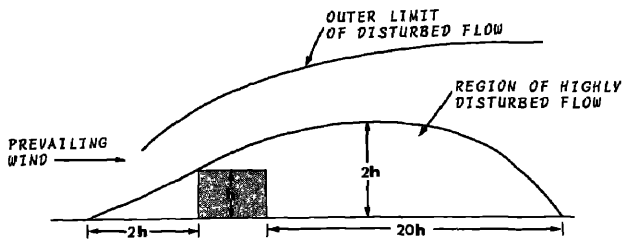


Figure 2 1.5.2-3
Effects of an individual building on air flow[71]

becomes a canyon and the winds are accelerated as they are forced to flow down it

Immediately downwind from a building one also finds an eddy formation. The shape and size of these eddies are dependent on the wind speed and the buildings dimensions. **Figures 2.1.5.2-2 and 3** summarize the effects of an individual building on the wind flow.

The urban heat island also affects the wind flows. In the core of the city where the heat island effect is most intense, the air rises Consequently, there is a tendency for a general inflow of the low level winds from the suburbs into the city centre.

EFFECT OF URBANIZATION ON CLIMATE		
Climatic Element	**Annual**	**Seasonal**
Temperature	0 7°C above rural values, length of frost free period 2 to 3 weeks longer	winter minima 1°C to 2°C above rural values
Heating Degree Days	10% to 15% less	
Sunshine and Radiation	Sunshine 5%-15% less Global radiation 15%-20% less.	Ultraviolet 5% less in summer and 30% less in winter
Air Quality	Pollution levels 10 times higher	
Wind	Mean 25% less extreme gusts· 10%-20% less frequent calms +5%-20% more frequent	
Relative Humidity	6% lower throughout the year (Effect smaller in residential areas)	8% lower in summer and 2% lower in winter.
Precipitation		14% less snowfall 5% to 10% decrease in rainfall

Table 2.1.5.3-T₁
Summary of the changes to climatic elements caused by urbanization[72 73 74]

2.1.5.3 Other Effects

Relative humidity fields in cities are affected by large paved areas. These surfaces do not retain moisture after periods of rainfall Consequently, they become hot and contribute to a dry urban atmosphere Some cities have sought to combat this effect by designating large areas as parks and planting them to grass However, in many urban centres this grass dries out during the summer and does not act as a moisture source Trees and shrubs are most effective because they put down their roots to the moist soil layers underneath and thus act as a moisture source throughout the summer In suburban areas lawn watering is so widely practiced that the moisture fluxes in these areas are felt to be similar to those measured in rural environments[75]

Other effects which can be partially attributed to the urban environment involve the reduction in direct beam solar radiation that occurs in highly industrialized areas The aerosols emitted from some industries cause the solar radiation to be reflected back to space They can also precipitate out on windows and other surfaces thereby reducing the effectiveness of passive solar heating.

Table 2.1.5.3-T$_1$ summarizes the urban effects in both the summer and winter The major effects of a city are to produce a heat island that decreases the demand for heating in the winter and increases the demand for cooling in the summer In addition, mean wind flows are reduced, thereby restricting the effectiveness of natural ventilation schemes

2.1.6 Procedures for Designing with Climate

2.1.6.1 Procedures for Incorporating Climatic Data into the Planning and Design Processes

To develop a plan that involves the selection of a site and for selecting the best design for minimizing energy consumption, the following steps should be taken

—Use the macroscale climatic information shown in **Section 2.1.2** to determine the energy demand for the appropriate region Site-specific data should be obtained for the closest weather stations by contacting one of the offices shown in **Table 2.1.2.1-T$_1$**

—Apply the information on topographical and urban effects from **Sections 2.1.4** and **2.1.5** respectively to obtain an estimate of the energy demand at the actual or potential building site

—Examine the various sites for the building on the property and choose a site that provides the maximum energy gain from natural energy sources and the maximum energy reduction from climate-based energy conservation strategies

—Based on the knowledge of the general climate shown in **Section 2.1.2** and the energy conservation methods that can be designed to take advantage of these climatic elements, develop a building plan and landscape design to minimize energy losses and wastages, and then build accordingly.

2.1.6.2 Procedures for Incorporating Climatic Data into the Energy Conservation Program

To incorporate climatic data into an energy conservation program the following steps should be taken

1 Choose one heating season as a baseline year **Table 2.1.6-T_1** shows the years during the past decade which were nearest to normal for 15 urban centres (If the energy consumption data is not available for this baseline year then follow step 3)
2. Determine the target value for the energy conservation program during the summer, prior to the commencement of the heating season and develop and implement a conservation strategy or make modifications to the buildings and property in order to achieve this new goal Unless some modifications have been made between the present and the baseline year, the target value should be some fraction of the energy used in the target year
3 If energy consumption statistics are not available for the baseline year, then take the consumption from another year and divide it by the factor shown in **Table 2.1.6-T_2** for the year with consumption data to get an estimate of the consumption expected during the baseline year.
4 Monitor temperatures during the heating season and compute the ratio of $\Sigma(HDD)_P/\Sigma(HDD)_B$,
where HDD_P is the number of heating degree days for the present season and
HDD_B is the number of heating degree days for the baseline heating season
5 Take the ratio computed in Step 4 and multiply it by the energy consumed during this heating season to obtain the adjusted energy consumption If the adjusted consumption is less than the planned consumption, it indicates that the energy conservation program has been successful On the other hand, if energy consumption exceeds the planned consumption reappraise the energy conservation goals and review the energy conservation program to make modifications where necessary

BASELINE HEATING SEASON	
Station	Heating Season (July to June)
London	1973—1974
Thunder Bay	1973—1974
Toronto	1973—1974
Windsor	1970—1971
Vancouver	1977—1978
Edmonton	1977—1978
Calgary	1974—1975
Regina	1974—1975
Winnipeg	1977—1978
Ottawa	1973—1974
Montreal	1974—1975
Quebec	1974—1975
Fredericton	1977—1978
Halifax	1977—1978
St John's	1977—1978

Table 2.1 6-T_1
Listing of the stations and heating season that should be used as the baseline season

FACTORS USED TO ESTIMATE ENERGY CONSUMPTION									
	Heating Season								
Station	1969 1970	1970 1971	1971 1972	1972 1973	1973 1974	1974 1975	1975 1976	1976 1977	1977 1978
Vancouver Int'l A	0.98	1.08	1.07	1.05	1.02	1.01	1.05	0.96	0.99
Edmonton Int'l A	0.93	1.03	1.03	0.95	1.05	0.93	0.89	0.86	1.08
Calgary Int'l A	0.96	1.03	1.06	1.00	1.04	1.01	0.92	0.83	1.10
Regina A	1.04	1.03	1.03	0.94	1.08	0.98	0.92	0.88	1.03
Winnipeg A	1.03	1.02	1.04	1.01	1.08	0.98	0.97	0.95	1.03
Thunder Bay A	1.03	1.00	1.04	0.99	1.02	0.96	1.00	1.04	1.04
Windsor A	1.07	1.01	0.97	0.96	0.96	0.99	0.94	1.09	1.10
London A	1.07	1.02	1.01	0.99	1.01	1.01	0.97	1.10	1.12
Toronto Int'l A	1.08	1.05	1.04	1.01	1.02	0.99	1.07	1.16	1.18
Ottawa Int'l A	1.06	1.04	1.03	0.99	1.01	0.96	1.01	1.03	1.05
Montreal Int'l A	1.08	1.07	1.04	1.02	1.04	1.01	1.03	1.06	1.08
Quebec A	1.03	1.03	1.07	1.04	1.05	1.01	1.04	1.06	1.04
Fredericton A	1.01	1.05	1.06	1.02	1.00	1.04	1.03	1.03	1.02
Charlottetown A	1.01	1.03	1.08	1.06	1.04	1.06	1.00	1.07	1.03
Halifax (Shearwater)	1.01	1.04	1.10	1.09	1.07	1.10	0.96	1.03	1.01
St John's A (Torbay)	0.94	0.95	1.03	1.07	1.05	1.08	0.99	1.01	1.00

Table 2.1.6-T_2
Factors which can be used to estimate the consumption during the year that best represents average climatic conditions

2.1.7 Architectural Response to Climate

Throughout the ages, humankind has been fashioning a built environment in order to provide shelter and accommodation for diverse private and communal activities.

Lacking our own mechanical means of modifying internal space conditions, our ancestors devised solutions which, of necessity, were closely linked to local climate and environment. Mark Twain's comments notwithstanding, people have in fact been doing something about the weather for quite a while, and in a quite natural way, at least until recent times. Historically, building design reflected the elemental characteristics, observed from season to season and from generation to generation. Climate, not stylistic preconception, was the major determinant of built form. Regional identity was given further expression by the employment of locally available materials which could be used to provide protection from diurnal and seasonal temperature and climatic change.

There is a fascinating correspondence between particular architectural elements, for example roof types, and certain climatic zones[76] and the similarities clearly extend beyond the coincidental.

2.1.7.1 American Indians

A vivid record of adaptation to climate has been provided by the American Indians as they moved across the Bering Straits and spread throughout the North American Continent.

V. and A. Olgyay have recorded this text book illustration and noted how the design of shelter developed in dynamic harmony with natural forces. For instance, in the extreme cold of the Northern Territories the low hemispherical igloo of the Eskimo deflected the arctic winds and presented the minimum surface exposure to them, **Figure 2.1.7.1-1**. Further south, on the cool, damp west coast, clustered groupings of heavy timbered, double shelled structures sheltered their inhabitants. The thermal insulation storage characteristics of massive adobe dwellings or excavations in solid rock

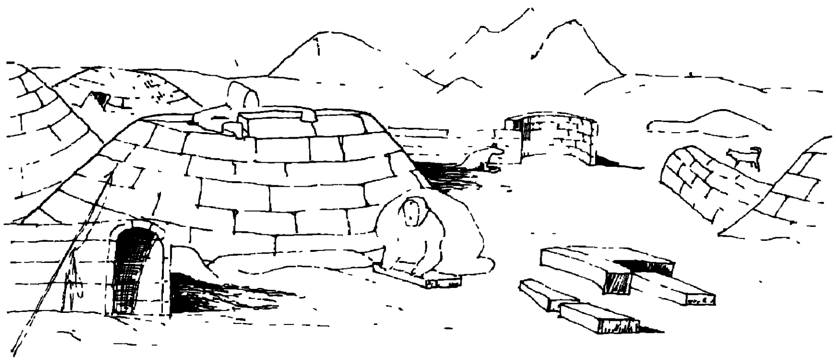
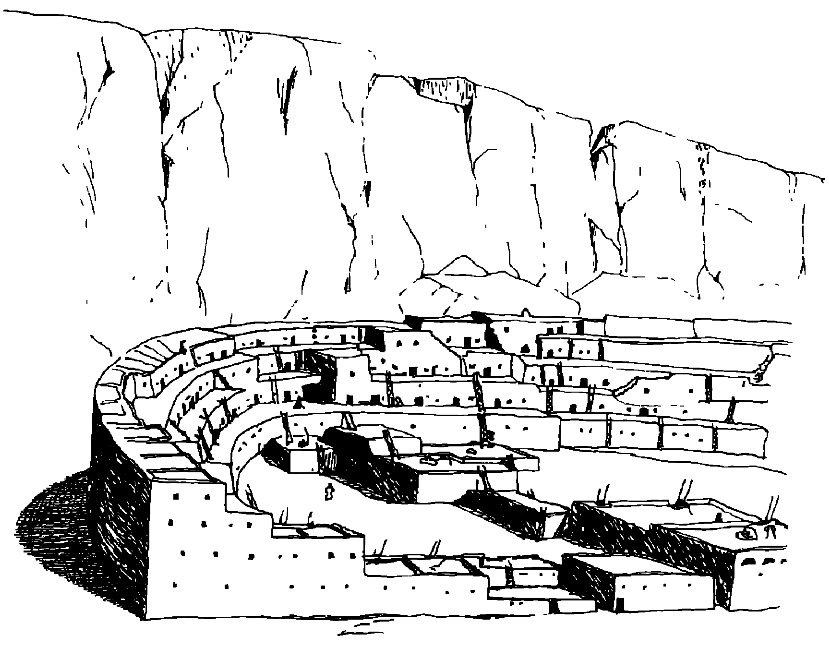


Figure 2 1 7.1-1
Eskimo dwelling (77)

escarpments were exploited by the tribes in the hot-arid south west Remarkable examples of such structures are the Pueblo Bonito in New Mexico, **Figure 2.1.7.1-2**, and the Cliff Palace which was



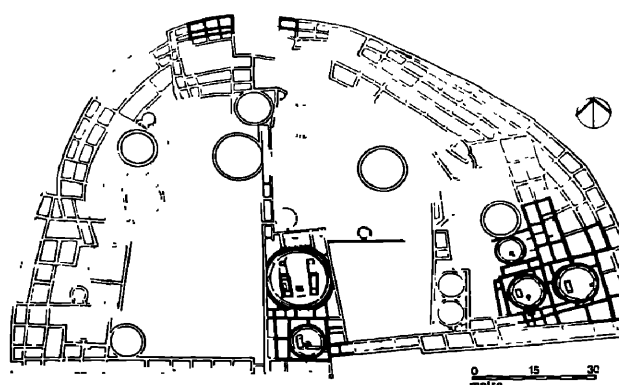


Figure 2.1 7.1-2
Pueblo Bonito, New Mexico (78)

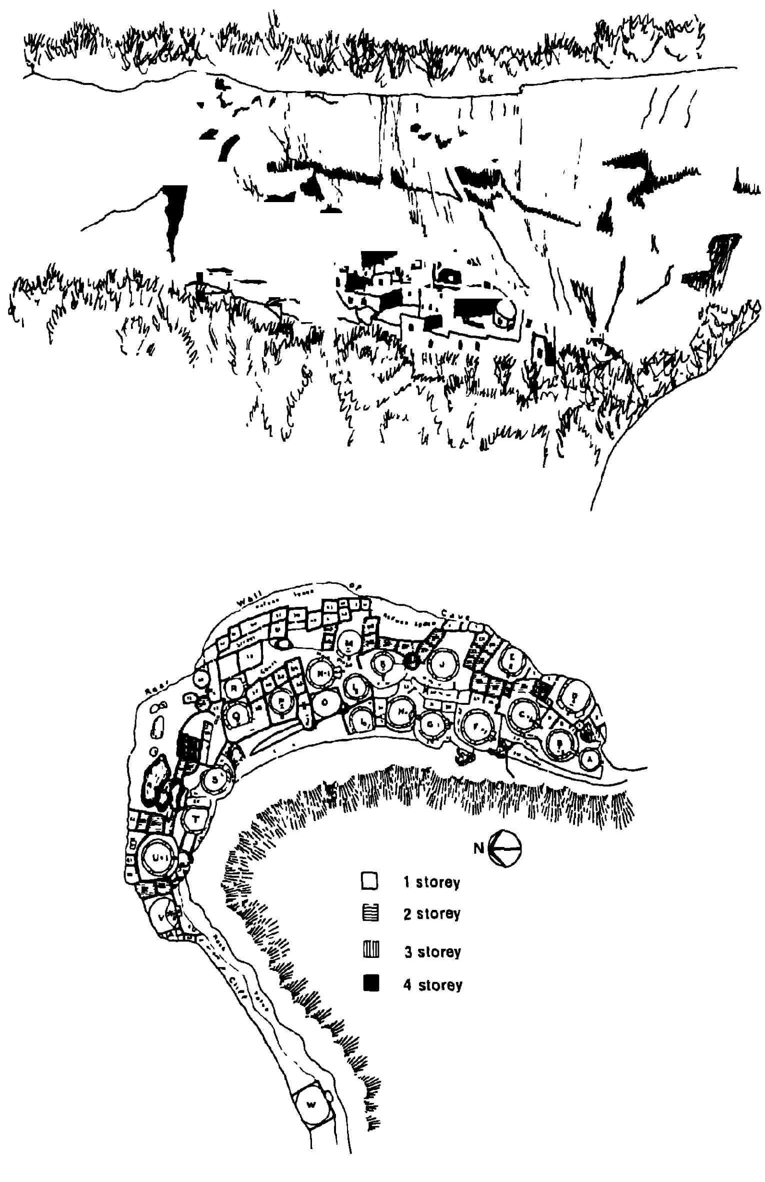


Figure 2.1.7.1-3
Mesa Verde, Colorado, illustration of location in rock face and plan[79]

carved out of the rock face of the Mesa Verde, Colorado, **Figure 2.1.7.1-3**. Up to 6 storeys high they were America's first apartment buildings Twentieth century builders have frequently erected taller structures but all too rarely have they reached the same heights of sophistication in terms of the sensible use of available resources.

Along the Gulf of Mexico, open shelters of light-weight construction, raised off the ground, provided the maximum opportunity for cooling breezes to bring relief from the hot and humid climate, **Figure 2.1.7.1-4**. The temperate area of the plains imposed fewer demands on its inhabitants who required structures principally to keep out wind and rain. The teepee and wigwam were their typical solutions, **Figures 2.1.7.1-5 and 2.1.7.1-6.**

Figure 2.1.7 1-4
Open shelters. Gulf of Mexico

Figure 2 1 7 1-5
North American teepee

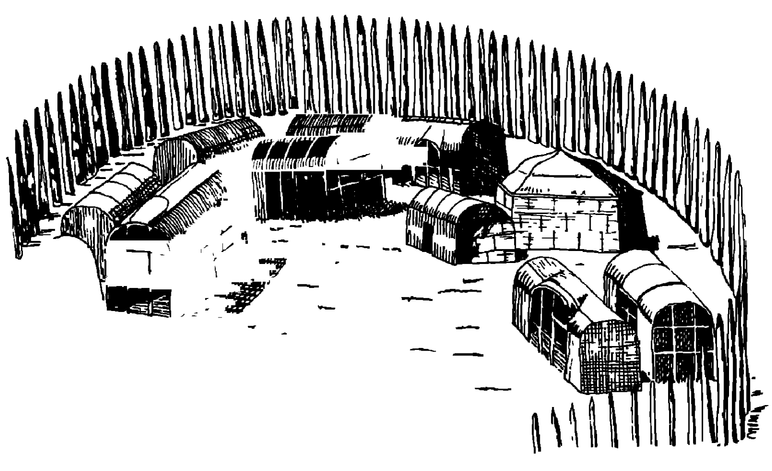


Figure 2.1.7.1-6
Wigwam

In-ground or pit dwellings, covered with earthen domes are found in a number of locations across the continent Like the igloo, they show how thoughtful builders used resources, in this case earth and tree branches, to good effect. Earth below the surface retains temperatures close to the yearly average and as a roof covering it provides thermal capacity which also would have helped to keep interiors cool in summer and warm in winter, **Figure 2.1.7.1-7.**

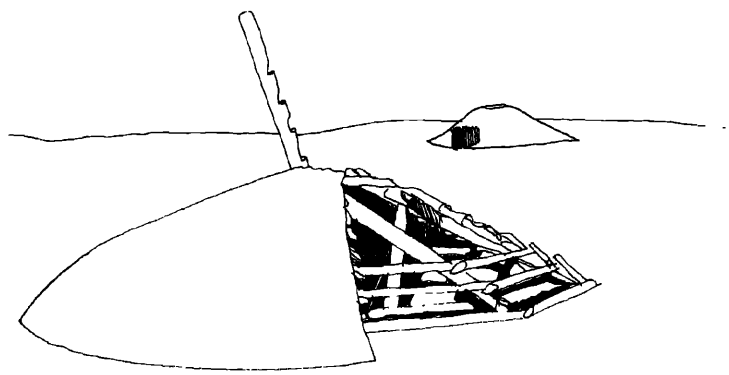


Figure 2 1 7.1-7
Below ground dwellings

Adaptations of this approach are found in many other parts of the world, particularly in areas of low humidity and intense sun and heat Probably the most outstanding, although virtually invisible, are the subterranean dwellings in Honan, China which are cut more than ten metres down into the loess

2.1.7.2 Western Asia and the Mediterranean

It is instructive to observe how ancient civilizations outside North America seized the opportunities for indoor comfort in climates that were frequently harsh and challenging. The techniques they employed ranged from the simple to the highly sophisticated

.1 **Assyrian and Persian Empires (4000 BC-4th Century BC)**: The contrast between the architecture of the Assyrian and Persian empires is as marked as the climatic differences which it reflects. The Tigris and Euphrates delta of lower Mesopotamia, a region of long and heavy rainfall, was characterized by massive walled structures of sun dried bricks that were raised on platforms above the surrounding swamps and floodlands. Windows were few and the heavy walls stored the sun's heat for the cool nights.

The Palace of Sorgon, Khorsabad further to the North, had walls 8 metres thick but it is possible this extraordinary dimension was required more to support a heavy vaulted roof than to keep out the heat of the Assyrian plains

In contrast, the hot dry climate of neighbouring Persia produced an architecture of open columned halls, exemplified by the palaces at Susa and Persepolis.

Wind towers and sun chimneys, singly or in combination, have been used in Persia and on the continents of Asia and Africa for centuries. The wind tower catches the prevailing breeze which is then deflected into the building or alternatively induces ventilation

by drawing air through it, **Figure 2.1.7.2-1**. The sun chimney or thermal stack creates air flow by convection and this can be enhanced by the installation of a solar collector at the top of the stack. Traditionally, replacement for the dispelled air was brought into the building by an underground tunnel During its passage the air temperature was lowered by evaporative cooling and finally by a fountain in the atrium or at the lower floor level, **Figure 2.1.7.2-2** and **2.1.7.2-3**.

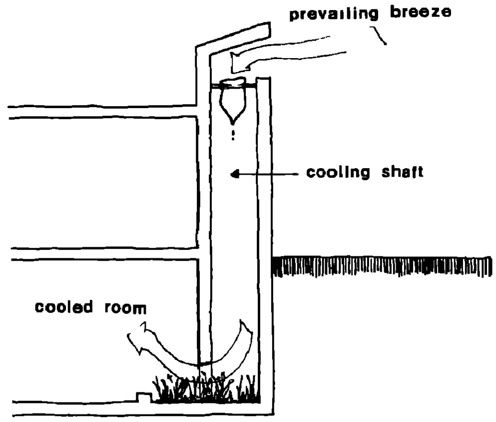


Figure 2.1 7 2-1
Windcatch [80]

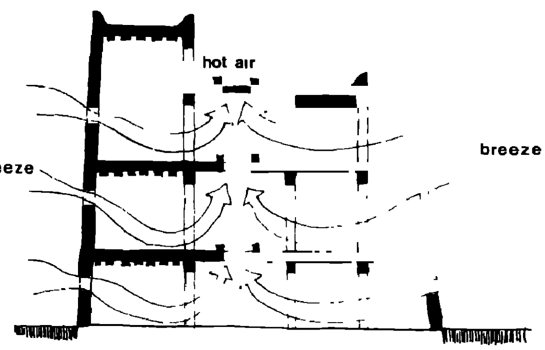


Figure 2 1 7 2-2
Stack effect Sahara dwelling [81]

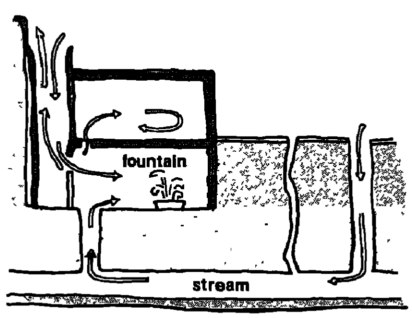


Figure 2.1.7.2-3
Passive cooling in a Persian building.[82]

Further examination of natural ventilation for buildings will be found in Section 3.9.2.

.2 **Greece and Rome**: The Greek climate favoured an outdoor life and most public ceremonies took place in the open air. Protection from the hot sun and sudden showers was provided by the porticos around the market places, by the stoae and the peripteral colonnades to temples and shrines. The latter kept the rain clear of external walls and sheltered them from the heat of summer sunshine

The Hellenic city of Priene, **Figure 2.1.7.2-4**, provides an example of town planning designed to take advantage of solar heating. The main streets of the city run east-west, following the contours of a south facing slope It is not known if the houses were designed in accordance with Socrate's advice that the south side should be loftier as 'in houses with south aspect the sun's rays penetrate into the portico in winter' while in summer 'the path of the sun is right over our heads and above the roof so there is shade' (83)

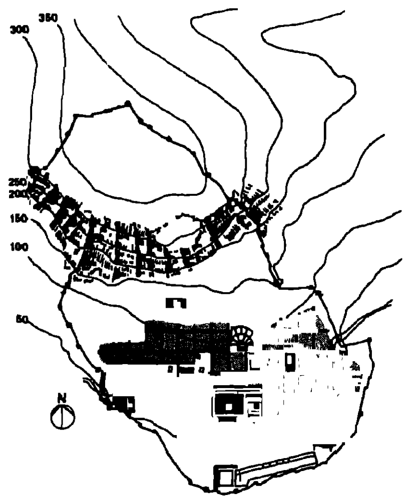


Figure 2 1 7 2-4
City of Priene (84)

In the days of Imperial Rome, Vitruvius directed the builders of thermae to plan their buildings so that the hot and tepid baths would be lighted from the south-west or, if circumstances prevented this, from the south 'as the set time for bathing is principally from midday to evening' (85)

The Romans acquired the art of glass making from Syria and Egypt They were probably the first to use sheets of glass in buildings and they used them to fill in the large clerestory openings created by the intersecting concrete vaults spanning the thermae. Glass was also used in the openings in south facing walls.

In the thermae of Caracalla, Rome, AD 211-217, the north-east side which was exposed to cold winds contained only four doorways while on the warm, south-west side large columned openings provided access to public gardens and shaded avenues of trees, **Figure 2.1.7.2-5.**

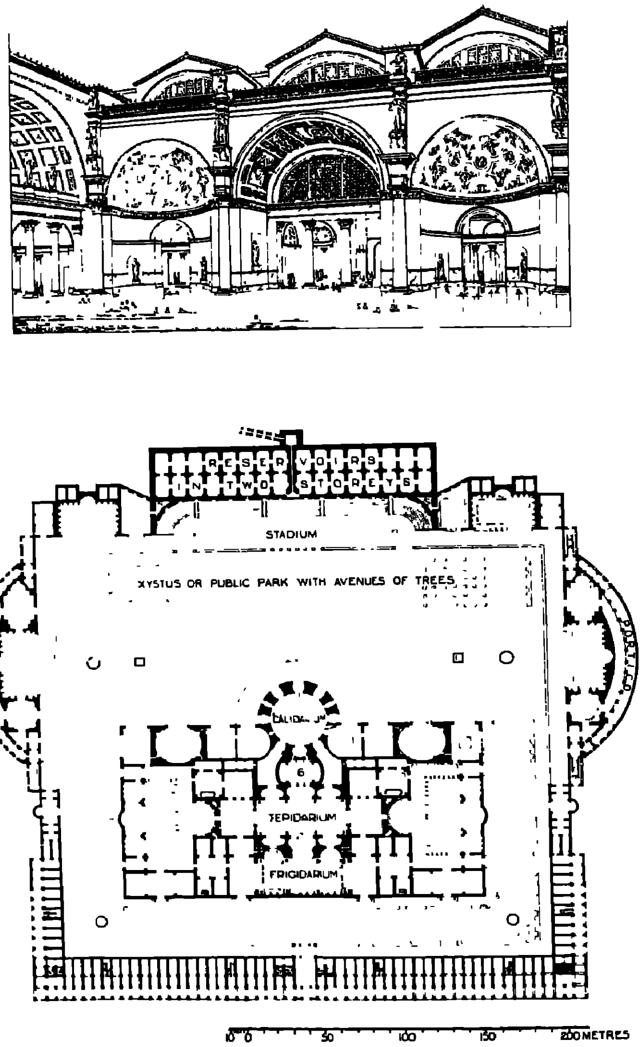


Figure 2 1 7 2-5
Thermae of Caracalla, Rome [86]

2.1.7.3 Europe

.1 **England and France**: Climatic influences are apparent in the differences between the cathedral architecture of England and France

While the typical great western portals of Amiens and Rhiems lead directly into the nave and aisles, entrances in England were usually from side porches facing south, which provided protection from the damp and penetrating English winds and rain, **Figure 2.1.7.3-1**.

In the flowering of traceried windows such as those in Kings College Chapel, Cambridge, we can witness the fulfillment of a number of aspirations in addition to the purely religious. Their radiant colours relieved the general dullness of the climate and filtered the direct sunlight when it broke through the clouds.

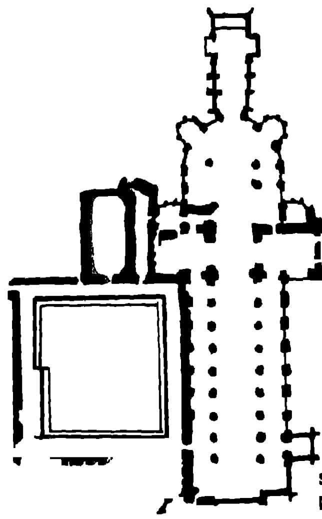


Figure 2 1 7 3 -1
Gloucester Cathedral, England

The word 'solar' (lat solarium—a sunny place or balcony) was adopted by the English in mediaeval times to describe the owner's private upper chamber over the great hall in castles and manor houses

.2 **Georgian Terraces**: The years from the eighteenth century to the present have been characterized by population increase and its concentration in expanding metropolitan areas Among the exceptions to the piecemeal development of major cities which took place during the industrial revolution are the splendid Georgian squares in London or the crescents in Bath

Although the Georgian terrace house originated in response to land-conserving principles and prevailing social attitudes its efficiency, also, in terms of energy conservation is obvious, **Figure 2.1.7.3-2.**

Unfortunately, in the twentieth century, especially in North America, the compact, energy-conserving row house was replaced in public favour by the separate, detached, suburban dwelling Sited, in isolation, on its own lot it is exposed on all four sides to the winter cold and summer heat and its existence is dependent on inexpensive, and available, energy for space heating and transportation.

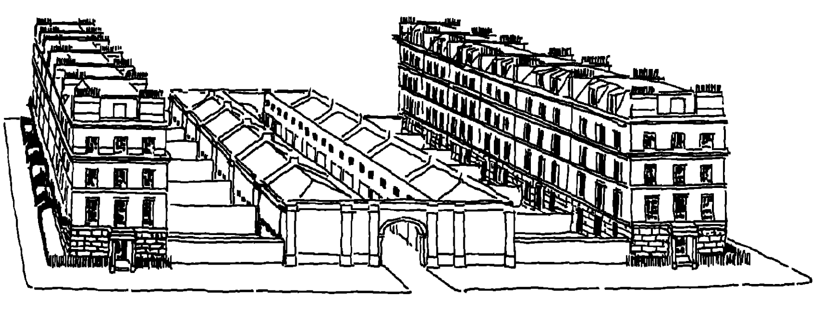


Figure 2.1.7.3-2
Georgian terrace house [87]

2.1.7.4 Summary

The foregoing has presented, in broad brush strokes, an indication of some of the ways in which architecture in different parts of the world has responded to climate In previous sections the reader was given a detailed description of the climatic conditions which we experience in Canada. An awareness and thorough understanding of the opportunities and challenges which they present is essential. With this we shall be able to create, in our own time, buildings which are not only energy conserving but also enriching and rewarding for their users.

2.2 Internal Spaces and Comfort

2.2.1 Thermal Comfort

Approximately two thirds of the energy consumed in Canadian buildings is used to modify internal space conditions, the major proportion being spent on heating

If nature had equipped our own bodies in the same way it has those of some of the other living creatures on this planet it would be quite a different story However, unlike the bear we cannot reduce our metabolism by hibernating nor like the Sable Island ponies grow thick fur coats

Considerations of the natural way so called lower forms of life can meet changing climatic conditions quickly reveals our own comparatively limited capacity for adaptation In brief, we need supplemental protection

Throughout the ages, in response to this obvious necessity, humankind has been fashioning forms of shelter, initially to ensure survival and ultimately to provide a reasonable degree of thermal comfort during the conduct of diverse activities In the process, the discovery of the warming fire and development of appropriate dress also became essential factors in the reconciliation of a wide range of natural conditions and human habitat

In retrospect, it is easy to see how the flood of inexpensive energy in the recent past upset the previously gradual evolutionary development of human shelter Also, expectations of the functions of buildings were radically altered as they became increasingly laden with highly energy-consumptive mechanical equipment The intent was to provide thermal comfort by systems which supplanted rather than supplemented the climate out-of-doors

More considerate, energy-conserving, alternatives are possible, desirable and necessary and are discussed later in the Handbook However, first of all, an examination of what is meant by thermal comfort will be of assistance

2.2.1.1 Definition of Thermal Comfort

The question, 'what is thermal comfort?' does not have an easy answer People are not alike 'thermally' or otherwise, and at the present time there is not a complete understanding of the physiological factors determining our thermal sensations, our sense of comfort or discomfort

ASHRAE has defined thermal comfort for a person as 'that condition of mind which expressed satisfaction with the thermal environment' It occurs within the 'comfort zone', a physiological definition of a range of thermal conditions wherein most of our bodily energy is freed for productivity and a minimum expenditure is required for adjustment to our surroundings [1]

Because it is not possible to satisfy everyone simultaneously, optimal thermal comfort is the condition in which most people are thermally comfortable

2.2.1.2 Factors Affecting Thermal Comfort

Briefly, our sense of comfort is affected by:[2]

—mean ambient air temperature.
—mean radiant temperature in relation to the human body
—mean air velocity to which the human body is exposed
—water vapour pressure in ambient air.

2.2 Internal Spaces and Comfort

In addition to the above environmental factors, our sense of comfort is also affected by
—activity level
—thermal resistance of clothing.

There are also other modifiers such as asymmetry of the radiant environment, fluctuations of air velocity, the vertical air temperature gradient and temperature of floor and other surfaces with which the body comes in contact Figure 2.2.1.2-1. In addition our perception of thermal comfort will be affected if there are any areas of local discomfort on the body such as on the fingertips or other extremities

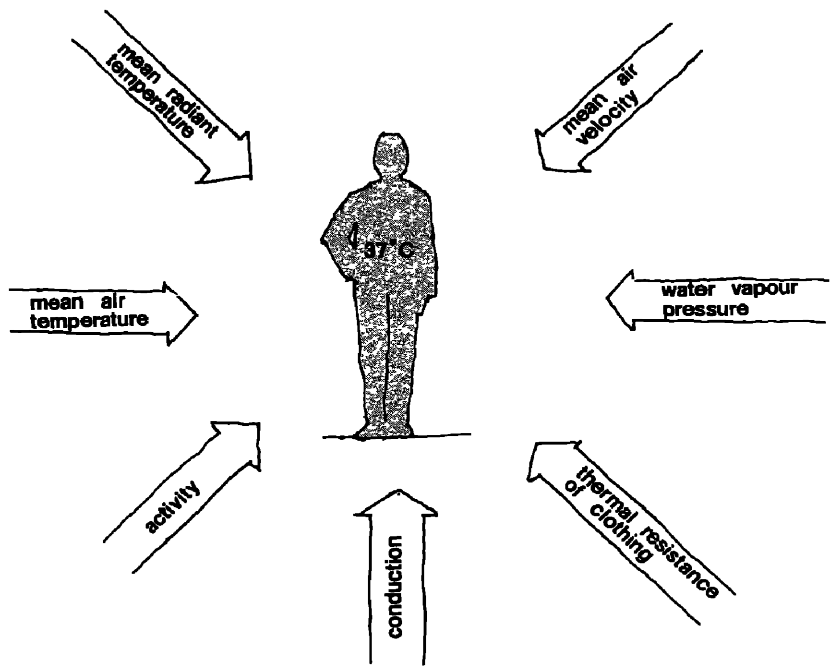


Figure 2 2 1 2-1
Environmental comfort paramaters

2.2.1.3 Physiological Conditions

Happy and healthy human life is possible as long as the human thermo-regulatory system can maintain a body temperature of around 37°C A requirement for this is the maintenance of a thermal equilibrium in which heat lost to the environment is balanced at the same rate by that resulting from the metabolic processes

Figure 2.2.1.3-1 illustrates acclimatization to heat by five subjects exposed to extreme conditions for a period of 24 days Some parts of the body, for example the brain, maintain constant temperature whereas other parts, such as the limbs, tolerate quite large changes [3] In such circumstances compensation is made by sweating (latent heat loss) or shivering (internal heat production), in between, the body controls its temperature by altering blood flow to the surface When we are warm, blood vessels in the limbs and body surface enlarge and with more blood flowing near the skin, heat escapes more rapidly to the environment (sensible heat loss) As we gradually feel cooler, less blood flows and the reverse process takes place

Such changes in blood flow may be regarded as changes in the thermal resistance of the body tissues from the core to the surface

On this basis, Humphreys[4] has constructed an equation to show the range of environments in which equilibrium can be maintained without perceptible sweating or shivering He has divided the heat transfer into three stages·
—Body core to skin
—Skin to outer surface of clothing
—Clothing surface to air.

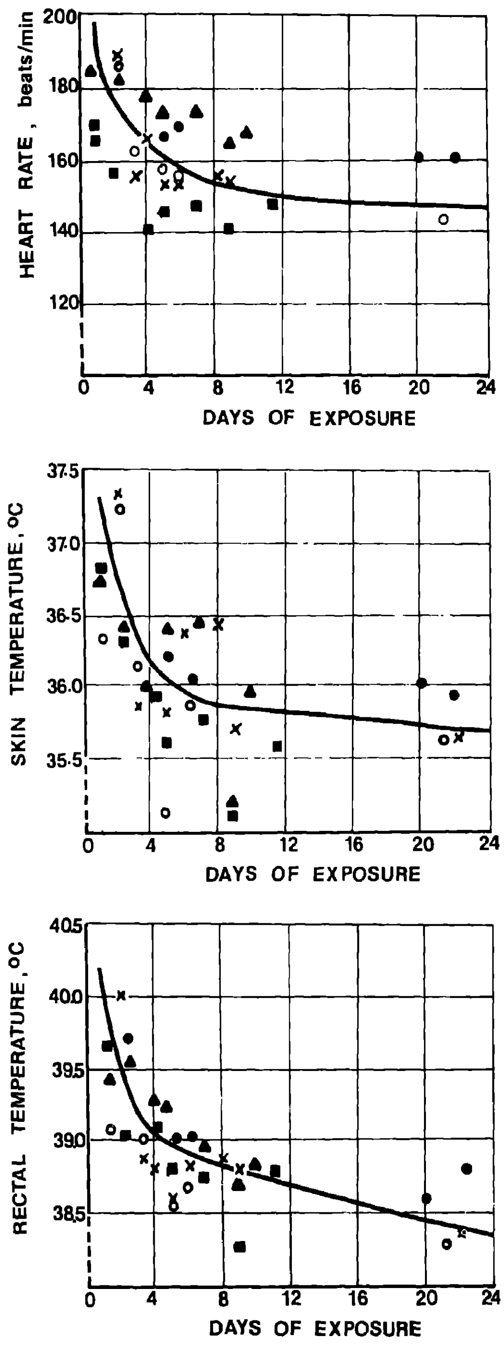


Figure 2.2.1 3-1
Acclimatization, heat recovery from daily exposure of five subjects to a room maintained at 40°C with 23% RH [5]

A description of the processes involved and development of his equation follows

1 Body core to skin·

The body is envisaged as a central core at uniform temperature surrounded by peripheral tissue with thermal resistance. The core temperature increases slightly during exercise but is independent of the temperature of the environment over a very wide range.

The tissue thermal resistance is smallest when the blood vessels are dilated and the heart rate is high

The equation of heat flow from the body core to the skin may be written as follows

$$M = (T_b - T_{sk})/R_b$$

$$\therefore \quad MR_b = T_b - T_{sk}$$

where M is the metabolic rate of heat production W/m²
R_t is the thermal resistance of the peripheral tissues, m² °C/W
T_b is the body core temperature, °C
T_{sk} is the area weighted mean skin temperature, °C

The metabolic rate is usually expressed in terms of the surface area of the body An approximation of the body surface area is obtained from the height-weight formula of Dubois, $A = W^{0.425} \times H^{0.725} \times 0.2024$, where A is the surface area in m², W the body weight in kg and H the height in m.

Metabolic rates for different activities are shown in **Table 2.2.1-T$_1$**. The vital processes of the body are accompanied by considerable heat exchange. This energy, derived from the oxidation of food, is utilized with a gross efficiency of 20% and the remaining 80% is expended as heat—a similar efficiency to that achieved by the fluorescent bulb For the same activity the metabolic rate is slightly lower for women than men and higher for children than for adults.

METABOLIC RATES	
ACTIVITY	W/m²
Sleeping and digesting	47
Lying quietly and digesting	53
Sitting	59
Standing	71
Strolling 2 5 km/h	107
Walking 4 2 km/h	154

Table 2 2 1-T$_1$
Metabolic rates for different activities [6]

(It is of interest to note that climate chamber studies in Kansas State University and at the Technical University of Denmark showed no significant difference between comfort conditions for men and women. The slightly lower metabolism for women is balanced by a slightly lower skin temperature and evaporative heat loss. However, as women tend to wear less clothing than men they may be slightly more sensitive to cold)

2. Skin to outer surface of clothing.

At the skin surface, and from the lungs, some of the metabolic heat is released by evaporation. The remainder (0.7 of the total

for resting people in thermal comfort and 0.6 for active people) is dissipated by conduction, convection and radiation to the clothing surface.

Thermal resistance of clothing is normally expressed in clo units. One clo equals 0.155 $m^2 \cdot °C/W$ and approximates the insulation afforded by a lounge suit with normal underwear The insulation value of clothing is achieved by the layer of undisturbed air which it provides around the body. If this layer is disturbed or penetrated the thermal insulation is reduced

The equation of heat flow from skin to outer surface of clothing may be written as.

$$kM = (T_{sk} - T_c)R_c$$
$$kMR_c = T_{sk} - T_c$$

where k is the proportion of the metabolic heat dissipated by means other than evaporation
R_c is the thermal resistance of the clothing in use expressed in terms of the Dubois area, m^2 °C/W
T_c is the area weighted mean outer surface temperature of the clothes and exposed skin, °C

3 Clothing surface to the air·
The equation of heat flow from clothing surface to the air developed by Humphreys is as follows

$$kM = (T_c - T_a)h_c + (T_c - T_s)h_r$$

where T_a is the temperature of the air, °C
T_s is the mean radiant temperature of the surroundings, °C
h_c is the coefficient of convection heat transfer, expressed in terms of the Dubois surface area, W/m^2 °C
h_r is the coefficient of radiant heat transfer, expressed in terms of the Dubois surface area, W/m^2 °C

A value of 13 $\sqrt{V}$ W/m^2 °C has been used for h_c V is the air velocity measured in metres per second

The equation may then be rearranged as follows:

$$kM\left(\frac{1}{h_c + h_r}\right) = T_c - \left(\frac{h_cT_a + h_rT_s}{h_c + h_r}\right)$$

The temperature $\frac{h_cT_a + h_rT_s}{h_c + h_r}$ is a weighted mean between T_a and T_s. It is the equilibrium temperatures of an unheated object having convection and radiation coefficients in the same ratio as h_c and h_r At low velocities T_a and T_s have almost equal weight.

Unless the difference between T_a and T_s is large the value of $\frac{h_cT_a + h_rT_s}{h_c + h_r}$ may be represented by a globe thermometer T_g The term $\frac{1}{h_c + h_r}$ is the thermal resistance between the clothing surface and the thermal environment and is given the symbol *Re*

The equation now becomes

$$kMR_e = T_e - T_g$$

4. Heat flow from body to air:
Adding the above equations we arrive at:

$$M(R_b + kR_c + kR_e) = T_b - T_g$$

From this equation, diagrams of comfort zones for various weights of clothing can be determined as shown in Figures 2.2.1.3-2, 3.

As these zones radiate from a single point they are wider at higher levels of activity. From this it may be concluded that an active person will be more tolerant of temperature changes than

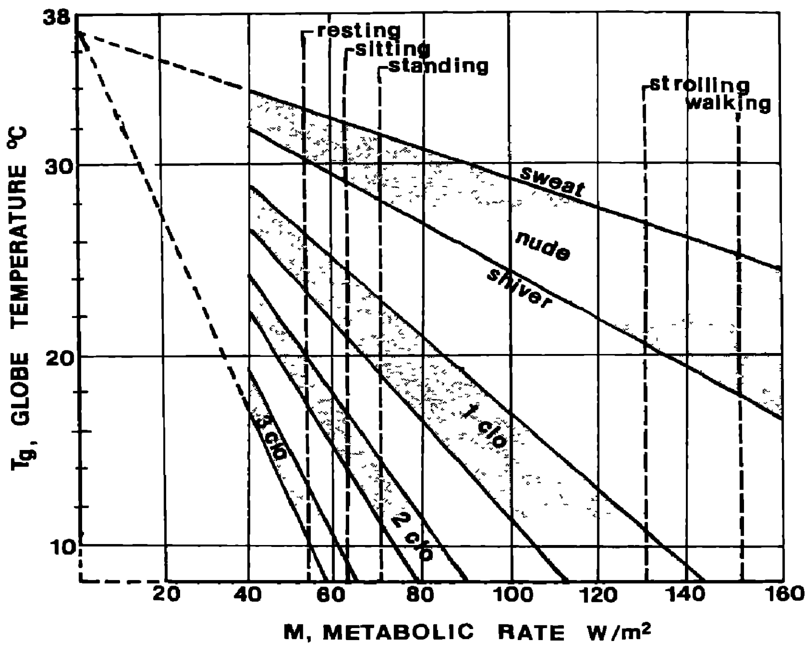


Figure 2.2 1.3-2
Comfort zones, air velocity 1 0 m/s.[7]

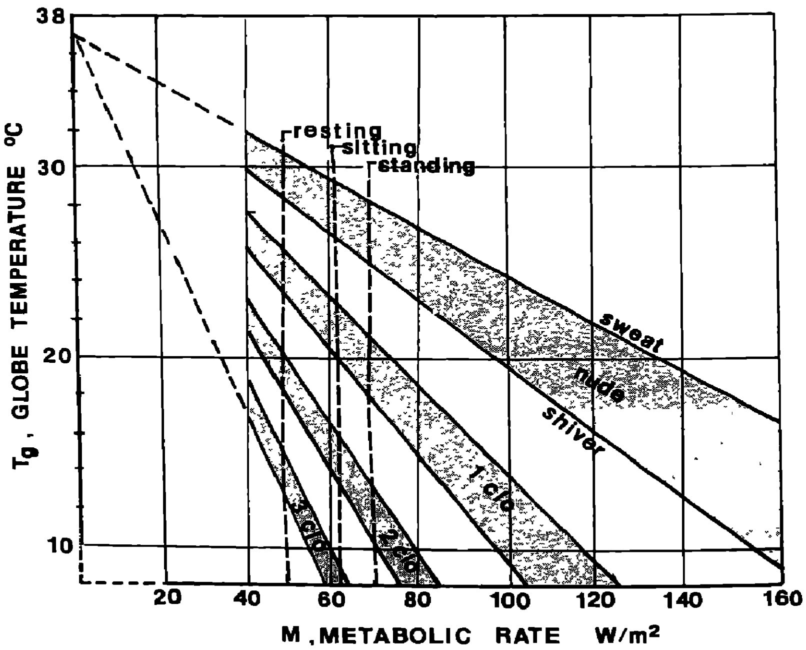
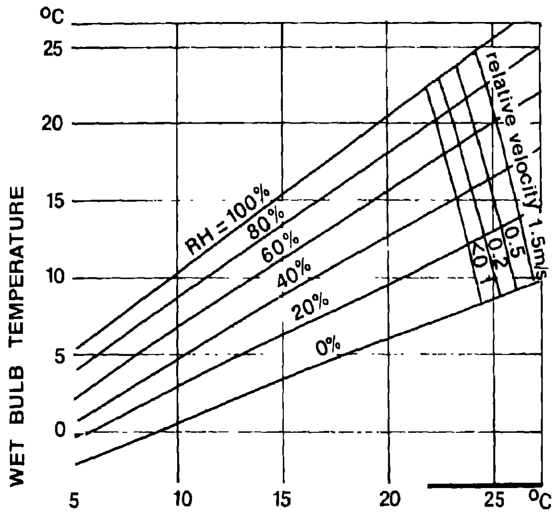


Figure 2 2.1.3-3
Comfort zones, air velocity 0 1 m/s[8]

an inactive one. It suggests for instance that temperatures in bedrooms warrant closer control than those in kitchens

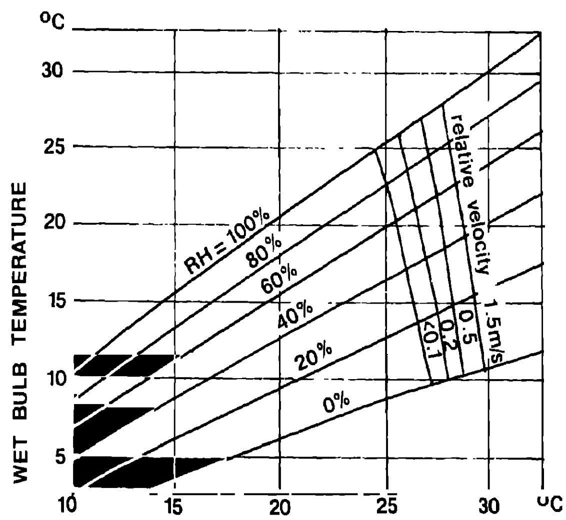
A line drawn parallel to the temperature axis shows that each clothing zone cuts off an equal temperature interval, indicating that weight of clothing should not determine the range of temperature to which a person is exposed

The figures also indicate that people can be in thermal equilibrium over a wide range of temperature if they are free to choose their clothing and activity The width of the comfort zone in terms of metabolic rate is greater at higher temperatures than lower.



AIR TEMPERATURE = MEAN RADIANT TEMPERATURE

SEDENTARY, MEDIUM CLOTHING (1 0clo)



AIR TEMPERATURE = MEAN RADIANT TEMPERATURE

SEDENTARY, LIGHT CLOTHING (0.5clo)

Figure 2.2 1 4-1
Combined influence of humidity and ambient temperature.[9]

2.2.1.4 Prediction of Thermal Comfort

The reader is referred to ASHRAE Fundamentals Handbook 1977, Chapter 8, for a comprehensive examination of physiological principles relating to comfort and health In the more than fifty years that ASHRAE has supported research on thermal comfort, temperature criteria defining that state have risen steadily. Changing living patterns, year round use of lighter clothing, diets and heightened expectations of indoor climate control are probably responsible for the trend.

According to Nevins, 1961, between 1900 and 1960 temperature criteria for thermal comfort rose from 18°C to 21°C DBT (dry bulb temperature) range to 24°C to 26°C DBT range. Effective Temperature for comfort increased from 18°C ET in 1923 to 20°C in 1941 [10]

A revision of the ASHRAE Effective Temperature Scale was commenced in the 1950's in view of recognized shortcoming's, that is, its overexaggeration of humidity at lower temperatures and underestimation of humidity heat tolerance levels.

Studies by Koch et al, 1960, showed humidity had negligible effect on comfort until 60% RH and 18°C DBT were reached. Dry bulb temperature, alone, was the determining factor below these levels.

Figure 2.2.1.4-1 illustrates the combined influence of humidity and ambient temperature Other studies have been conducted by the Institute for Environmental Research at Kansas State University since 1963 and involved the thermal comfort of clothed, sedentary subjects (1600 college-age students). The subjects, dressed in standard clothing of 0.601 clo reported their thermal sensations on a seven category ballot One or more voted 'comfortable' over a range of 16.7°C to 36 6°C DBT with a mean of 26°C and RH of 50% [11]

.1 **Comfort Zone**: The New Effective Temperature (ET*) Scale is shown in **Figure 2.2.1.4-2** and the shaded area represents the Comfort Zone recommended in ASHRAE Comfort Standard 55-74 This chart applies to altitudes from sea level to 2134 m, a mean radiant temperature which is nearly equal to dry-bulb air temperature, air velocity of less than 0.2286 m/s and sedentary, lightly clothed people.

Figure 2.2.1.4-3 shows the new ET loci which form part of **Figure 2.2.1.4-2**.

Based on KSU and ASHRAE equations the most commonly recommended design conditions for comfort are
—ET* = 24 5°C
—DBT = MRT = 24.5°C
—RH = 40%
—Air velocity less than 0.23 m/s.

Obviously, demands for energy conservation will necessitate adjustments to the upper and lower limits for summer and winter thermostat settings. Equally, attitudes towards dress are also likely to change.

2.2.1.5 Psychological Conditions

No energy savings seem to be involved in the colour conditioning of rooms, according to studies by Fanger et al Neither does noise level (40 db-85 db) appear to have any psychological effect on a person's thermal comfort.

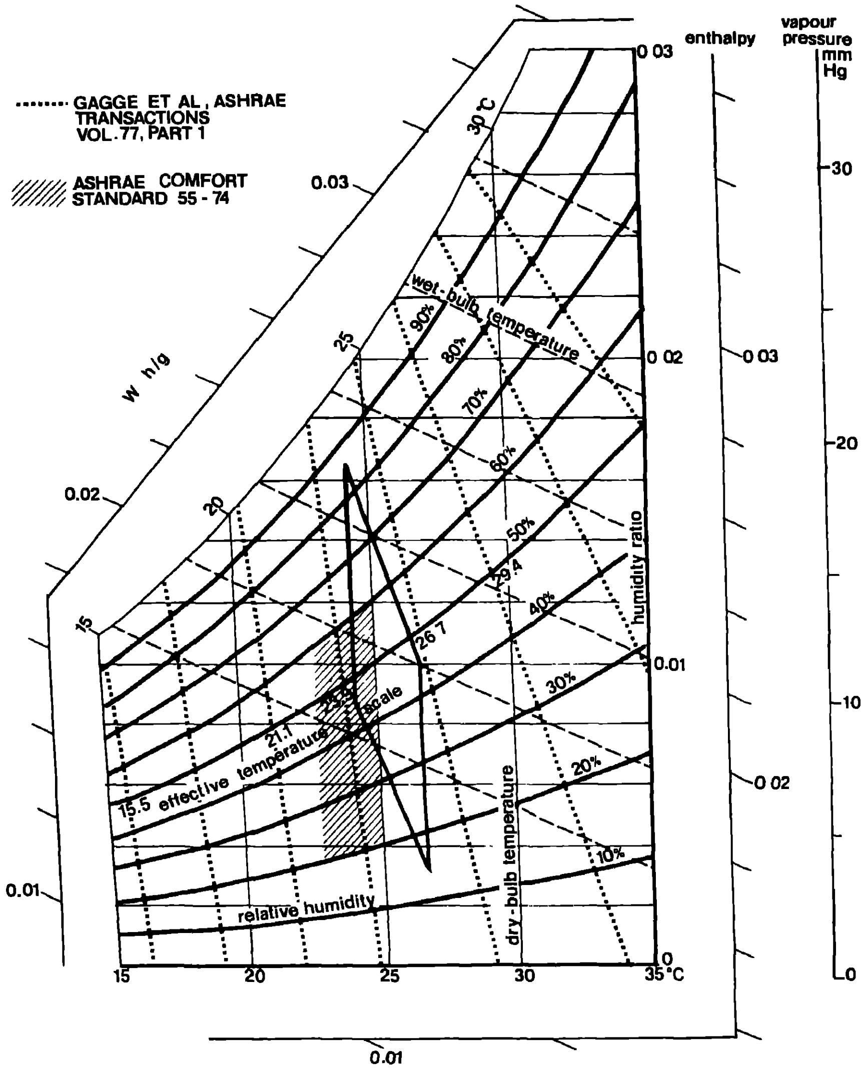


Figure 2 2 1.4-2
Effective temperature scale [12]

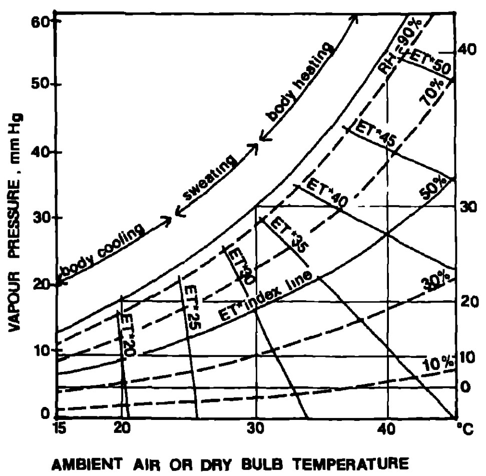


Figure 2.2.1.4-3
Effective temperature scale (ET*) based on loci of constant wettedness caused by regulatory sweating.[13]

2.2.1.6 Summary

A large number of studies have been undertaken on human response to the thermal environment It is of interest to note that in the last generation of commercial buildings in the western world attention has shifted from problems of keeping interiors warm to prevention of overheating. For example, a 1948 survey of pre-war offices in London, England showed that 85% of their occupants wanted sunshine in their offices but only 8% were concerned that they should not be too hot The results of a survey taken in 1961 are in marked contrast with as many as 40% of respondents indicating that they were sometimes too hot in summer.[14]

This may not be surprising considering the number of symmetrically configured buildings, the facades of which are treated identically regardless of exposure

It should also be acknowledged that not all energy savings can originate in the design of the building In other words, simple and inexpensive modifications in behavioural patterns and clothing can also achieve significant results. In connection with the latter, Fanger[15] has expressed a need for more studies on clothing habits, the development of new, light weight clothing ensembles with easily adjustable clo value and the development of thermally, rationally designed uniforms for different occupations Without underestimating what can be achieved now, their results, obviously, could be of assistance in the creation of space conditions which reflect a sensible reconciliation of personal thermal comfort, climate and resources

2.2.2 Dynamic Responses to the Environment

Despite increasing research in recent years, the human-environment relationship is not yet fully understood However, this does not relieve the design professional from the duty of creating an adequate environment for the satisfaction of a wide range of human needs Thus far, we have managed to solve our design problems by using professional experience, intuition and creative ingenuity But it has been observed that a conventional approach to design tasks appears to fail, especially in such areas as military, mental and physical health institutions, in extreme environmental situations and in industry

Recently, not only has there been considerable concern related to high-rise accommodation and the well-being of a family in a high density environment but we have also been exposed to vivid descriptions involving various pathological phenomena originating from the shoulder-to-shoulder situation A relative newcomer on the scene is a concern for the quality of working place as well as life outside it.

2.2.2.1 Adaptation to Environment

The gap between technological progress (survival strategies) and our ability to adapt to and digest changes at matching speeds is enormous Even without an 'energy crisis' such a gap would lay a great burden on designers' shoulders, but should we encounter energy exhaustion or unacceptably high costs for conventional forms of energy, the restructuring of our environment might be drastic and the designer's task would become paramount

Perhaps one way to better understand our relationship to the environment would be to visualize a human being as a circle. Any outside deforming force is balanced by a resistance force As long as this takes place within the elasticity thresholds, we are dealing

with a healthy dynamic relationship between individuals and their surroundings (changes in light intensity are balanced by pupil responses, low temperatures by increased liver activity, muscle tremor and goose pimples, and high temperatures by perspiration, etc.) Continuing this analogy, if the outside forces are strong enough to deform beyond the elasticity limits, then the original form (state of the body) may suffer from a permanent dent

Another way to handle deforming forces is by prevention We shield ourselves from environmental extremes Protective shields or filters allow only safe dosages to get through (sunglasses, an umbrella, a fur coat, a single-family house, a skyscraper)

In order to complete our simplified abstraction of the human-environment relationship, we have to consider the following concepts

.1 **Human beings are not suspended in a vacuum.** The social milieu is a source of powerful deforming as well as remedial forces Several experiments show that who sits beside us on the assembly line is a more important factor than the noise or light level

.2 **We are not a constant.** Human beings themselves, are the subject of change during their lifetime. Each stage, childhood, adolescence, and senility is characterized by responses to the environment We design a different working, learning and recreational environment for different age groups

.3 **Human responses to the environment are determined also by genetic make-up.** During evolution humans acquired the ability to respond continuously to a wide range of stimuli from their surroundings We still react to exposure to the movement of heavenly bodies Even when we are completely shielded from changes in temperature and natural light, we cannot escape the physiological and mental consequences of the cosmic forces This becomes quite obvious when we attempt to design a windowless environment, for example

.4 **We are part of past collective efforts and accomplishments.** The methods of sheltering against hostile environmental forces has always been a product of available materials, tools/technology, and ingenuity But as soon as the form is ritualized, and petrified, it is not often allowed to be significantly altered even in response to drastic changes in climate or in geographic location. For example, our present housing stock was modelled by a much warmer climate The cultural milieu is a double-edged sword It can harm at a time when change and adaptation are necessary.

Despite our increased knowledge of our physical and mental dimensions, we still do not have a miraculous system—a super-computer which can precalculate a comfortable living environment out of an all-dizzying complexity, or achieve an environmental conducive to creativity, or one which could quadruple productivity on the assembly line.

2.2.2.2 Evaluation of Built Environment

Many environmental parameters are measureable by instruments (temperature, humidity, noise level, ..), but since the mechanics of multi-sensory perception, (feelings of comfort/discomfort, for example) are not fully understood, ultimately the only yardstick available is our own selves.

The evaluation and testing of the built environment has two phases first, the checking of physical standards expressed in physical terms, secondly, the final human appraisal

The human metre, (the evaluating team) should be selected from a representative population of inhabitants or users As in any other metre, it should be calibrated This would include a physical examination, the checking of vision, hearing, and thresholds of individual sensitivity. Furthermore, the team would evaluate certain environmental conditions in the laboratory

It is recommended that words be used for evaluation rather than numbers or an alphabet form Discomfort, for example, would be expressed as 'just perceptible', 'just acceptable', 'just uncomfortable' and 'just intolerable' Later, for computer use, it could be translated into numbers, (1, 2, 3, 4) and 'no-go' (later translated into 0, 1) The calibration process would be the same.

Furthermore, there is considerable literature available which describes these and various other sophisticated methods for testing the built and social environment by using the human metre

2.2.2.3 Optimum Environment

In an effort to design an 'optimum environment' for a particular purpose, we must remember that, during our long evolution, we have always lived close to nature and have been continuously exposed to a bombardment of hostile and challenging environmental forces Survival pended on coping with these forces and maintaining a healthy dynamic equilibrium A completely shielded, sterile environment can cripple or even kill (total sensory and social deprivation).

Thus, our goal should be to create an environment of controlled disturbance. It contains three basic ingredients rhythm, pulse and change The output (performance) of the man-environment system is a measure of the designer's success This leads to a broadening and expansion of the design process

First, homework has to be done Often it appears that designers of zoos possess a better knowledge of animals than designers of cities, and buildings, do of their human users Age, sex, education are all necessary data for design consideration. (Is the colour yellow associated with a yellow rose or with yellow fever?)

Designers must include other specialists, experts in other scientific disciplines (such as psychology, physiology, human engineering, etc) in their design teams The use of three dimensional representations becomes mandatory. They should be full scale wherever practical. Finally, the designer must evaluate and test the existing environment One cannot stress enough the importance of continuously monitoring the use and performance of previously designed buildings.

The time and energy spent in the design stage does pay high dividends. Ignoring the role of human nature in the man-made environment could lead to very expensive adjustments later or even to complete abandonment (e.g. the Pruitt-Igoe Housing Project). This general rule has a very special bearing on our times, times which are characterized by the problems of supply and cost of conventional forms of energy.

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3.0 Environmental Control and Energy Systems

Contents

Continued

3.0 Environmental Control and Energy Systems

Continued

3.0 Environmental Control and Energy Systems

Continued

3.0 Environmental Control and Energy Systems

3.15 Domestic Equipment and Appliances

3.15.1 **Energy Consumption and Cost** — Alexander Mozes, C M , P Eng., MEIC

3.15.2 **Other Constructional and Design Considerations** — "

3.16 Glossary of Mechanical Terms

Text References

*The SNC Group
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3.1 Heat Gain

3.1.1 Sources of Heat Gain

Heat gain is the amount of heat instantaneously coming into and/or generated within a space The actual load is defined as that amount of heat which is instantaneously added or removed by the air conditioning equipment

The following section is based on information contained in the *Handbook of Air Conditioning System Design* published by the Carrier Corporation [1]

Heat gain is classified by
—the mode in which it enters the space
—whether it is sensible or latent, the sensible heat gain creates a rise in the temperature of the conditioned space, whereas the latent heat gain is due to the addition of moisture to the space without effect on the space temperature.

The first classification is necessary since different criteria are used to calculate the different modes of energy transfer The second classification, sensible or latent, is important, for proper selection of the cooling equipment

Sources of heat gain are divided in two categories
—heat gain from external sources
—heat gain from internal sources

3.1.1.1 Heat Gain from External Sources

The heat gain from external sources occurs in the form of

.1 Solar Radiation:
—sun rays entering windows and glazed surfaces
—sun rays striking the walls and roof, increasing their temperature due to absorption of radiant heat which causes heat to flow into the space.

Heat gain amount for glass could be reduced, for example, by using tinted glass or reflective glass

Glass type	*Heat gain reduction*[2]
amber tint	30%
dark blue tint .	40%
grey green tint	. 50%

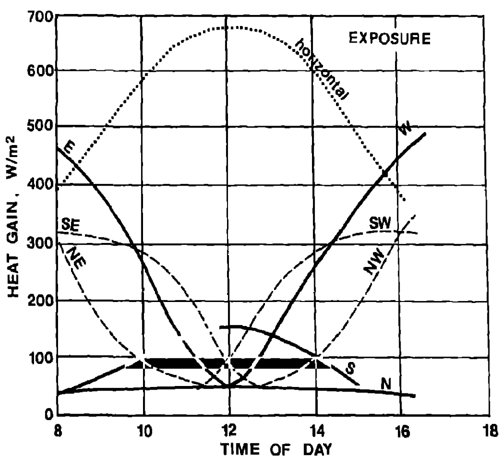

Figure 3.1.1.1-1
Solar heat gain, 40° north latitude, June 21st

HEAT GAIN (W/m²) DUE TO SOLAR RADIATION					
	Hour				
Exposure	08:00	10:00	12·00	14.00	16·00
North	34	40	40	40	34
Northeast	318	85	40	40	34
East	460	270	40	40	34
Southeast	309	281	96	40	34
South	34	99	153	99	34
Southwest	34	40	96	281	309
West	34	40	40	270	460
Northwest	34	40	40	85	318
Horizontal	380	595	672	595	380

Table 3 1.1 1-T1
Relative amounts of heat gain due to solar radiation for ordinary glass, double pane, under various exposure for 40° north latitude (June 21st period)[3] (ref Figure 3 1 1 1-1)

.2 **Heat Conduction Through Exterior Surfaces**: A higher outside ambient temperature causes heat to flow into the space through all exposed areas of the structure

.3 **Heat Transfer Between Adjacent Areas**: Heat flows through interior partitions, ceilings and floors which separate areas at different temperatures

.4 **Moisture Transfer Through Building Materials**: A higher vapour pressure surrounding the conditioned space causes water vapour to flow through the building materials This gain is significant only in low dew point conditioning.

.5 **Air Leakage**: Heat gain as a result of infiltration of outdoor air results in localized sensible infiltration and latent heat gains.

.6 **Infiltration Caused by Stack Effect**: The variations in temperatures and humidities produce differences in density of air between inside and outside of the building In tall buildings this density difference causes summer and winter infiltration and exfiltration (Ref **Section** 3.3.4

.7 **Heat Gain as a Result of Ventilation**: Outdoor air is usually necessary to flush out the space and keep the odour level down This ventilation air increases heat gain and humidity which may have to be removed by the air conditioning equipment

3.1.1.2 Internal Sources

The heat gain from internal sources occurs through heat generated within the space by.

.1 **Occupants**: The human body releases heat and moisture (i e sensible and latent heat) through metabolism The amount of heat generated and released depends on surrounding temperature and on the activity level of the person. Greater activity produces higher level of heat gain and a proportionately higher level of the latent heat component. (Ref. **Section 2.2** Internal Spaces and Comfort).

.2 **Lights**: Luminaires convert electrical power into light and heat Some of the heat is radiated to the space above the suspended ceiling and some below. The convection portion of the heat may be stratified.

Incandescent lights convert approximately 10% of the electrical input to the bulb into light with the rest being generated as heat within the bulb and dissipated by radiation, convection and conduction. About 80% of the electrical input is dissipated by radiation and only about 10% by convection and conduction.

Fluorescent lights convert about 24% of the electrical input to the luminaire into light, with about 25% being dissipated by radiation to the surrounding surfaces. The other 50% is dissipated by convection and conduction. In addition, approximately 25% of the electrical input to the luminaire is generated as heat in the ballast, e.g. a luminaire of 160 W capacity will require 200 W of electrical input.

.3 **Appliances**: Electric, gas, or steam appliances release heat into interior space.

.4 **Calculating Machines and Computers**: Electric calculating machines and computers generate some heat. Reference to manufacturer's data must be made to evaluate the heat gain, and a usage or diversity factor should be taken into account.

.5 **Motor Driven Machinery**: Motor driven machinery creates a significant heat gain, particularly in industrial applications. Motors and driven machinery dissipate heat according to type of machine and their location with respect to the conditioned space and the driven machine.

As an example, heat gain from a 746 W motor driving a fan would be as shown in **Table 3.1.1.2-T_1**.

HEAT GAIN FROM A MOTOR		
Location with respect to conditioned space	Heat gain to the space	
	watts	% of nameplate power
Motor in the space driven machine in space	937	125
Motor outside the space driven machine in space	746	100
Motor in the space driven machine outside the space	187	25

Table 3.1 1.2-T_1
Heat gain from a 746W motor driving a fan [4]

.6 **Hot Pipes and Tanks**: Steam or hot water pipes running through the conditioned space, or hot water tanks in the space, add heat In many industrial applications, tanks are open to the air, causing water to evaporate into the space resulting in increased latent heat gain.[5]

For example:

(a) A 50 mm nominal diameter bare steel pipe would produce the following heat gain to the space per unit of length exposed at ambient temperature of 21°C.

Pipe content	*Heat gain W/m²*
Water 90°C. . .	180
Steam 120°C.	.290

—Application of 25 mm of common insulation to the same pipe would reduce the heat gain by some 75%.

(b) A painted, uninsulated metal tank open to the air and containing water at 65°C, would represent the following heat gain per surface unit to a 21°C space:

Source	*Heat gain W/m²*
tank sides	1850 (sensible)
evaporation from surface. .	2140 (latent)

.7 **Process and Other Miscellaneous Equipment:** The 'miscellaneous' category of heat gain in commercial office buildings can mean heat generated by the duplicating and other office machinery, elevators etc. This usually tends to be a small part of the total heat gain However, in industrial buildings, process work may contribute a major portion of the entire space load and may require special design attention.

3.1.2 Heat Load Analysis

To understand the potential for energy conservation in buildings the first step is to analyse properly the total effect of the building heat gains and losses in a broad context, that is, by means of a building load analysis. The following section is based upon information contained in *Conserve Energy by Design* by Trane Co [6]

3.1.2.1 Building Loads

The building load is usually dependent on the following factors:
—outside air temperature—based on the local climate
—inside air temperature—comfort design criteria of building
—ventilation requirement—based on the building size, space and use
—solar radiation—based on the building orientation, configuration and construction
—lighting level—based on the decorative internal arrangement and purpose of the building
—miscellaneous internal processes inside the building
—transmission of heat through the building, outside-to-inside or vice versa

In order to carry out a useful building load analysis, obviously detailed information relating to the foregoing is required. This would include:
—climatic data: temperatures, solar radiation, wind, humidity and seasonal variation etc
—building data: orientation, size, shape, mass, air, moisture and heat transfer characteristics
—operational characteristics: temperature, humidity, ventilation, illumination, control mode for occupied and non-occupied hours.
—internal heat generation: lighting, equipment, number of people during occupied and non-occupied periods
—mechanical equipment: design capacity, part load profile, relative location of equipment in building.

3.1.2.2
ɪalance Model

The combined effect of the heat gains and losses are analyzed in order to establish a heat balance of a building as shown in the visual representation of a model (**Figure 3.1.2-1**) This indicates the relationship between loads along the vertical axis, and outside air temperatures, along the horizontal axis Heat gains are shown above the horizontal reference and heat losses vertically below it A building obviously can have simultaneous heat losses and heat gains

The balance point is that theoretical condition where building gross heat gains equal gross heat losses It has nothing to do with the action of an air conditioning or heating system on building loads. Note that the solar loads do not materialize at night or on cloudy days (Ref **Section 3.10**) Total heat gains less solar, as well as with solar, are important values. Total heat losses include transmission and ventilation.

In this particular model, heat gains equal heat losses whenever the outdoor air temperature is above 11°C without sunshine, and 5°C with sunshine. Theoretically, this means that at these break-even temperatures the building needs no heat energy input nor does it reject any heat In this analysis, the heat balance point is not as important as the magnitude of the heat losses or gains and their inter-relation in order to assess the potential for energy conservation. Thus, we can see the potential for trading heat gains for heat losses through changes in the factors mentioned above and also through a proper air conditioning system

If a building is left unoccupied or partially occupied for long periods, this should be considered carefully, since the energy balances under these conditions can vary considerably from the occupied mode. Transmission losses and gains, of course, are unaffected even though a building is unoccupied However, in these circumstances, ventilation is usually turned off and this component of the load, then completely disappears except for infiltration There are no occupant loads and the lighting load consists only of security or decorative lighting

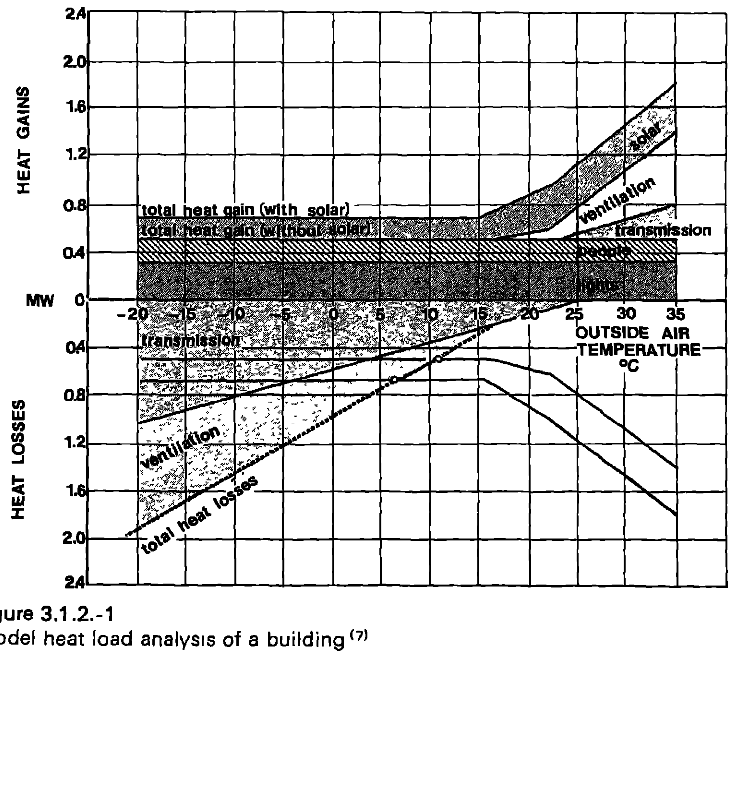

Figure 3.1.2.-1
Model heat load analysis of a building [7]

3.1.2.3 Sample Load Analysis Curves

Although it is difficult to categorize load analysis models specific to certain types of building due to many variables affecting the shape of the curve, the sample load analysis curves (**Figures 3.1.2-2 to 5**) show various shapes typical to certain building characteristics.

Figure 3.1.2-2 represents the load analysis of an office building in relatively cold area and, obviously, the effect of weather is noticeable This is a quite large building with a relatively small effect of transmission compared to internal heat gains. This relationship shifts the energy balance point to a lower temperature

Figure 3.1.2-3 shows the effect of large internal gains compared to small losses, in a government building. In this example the lighting

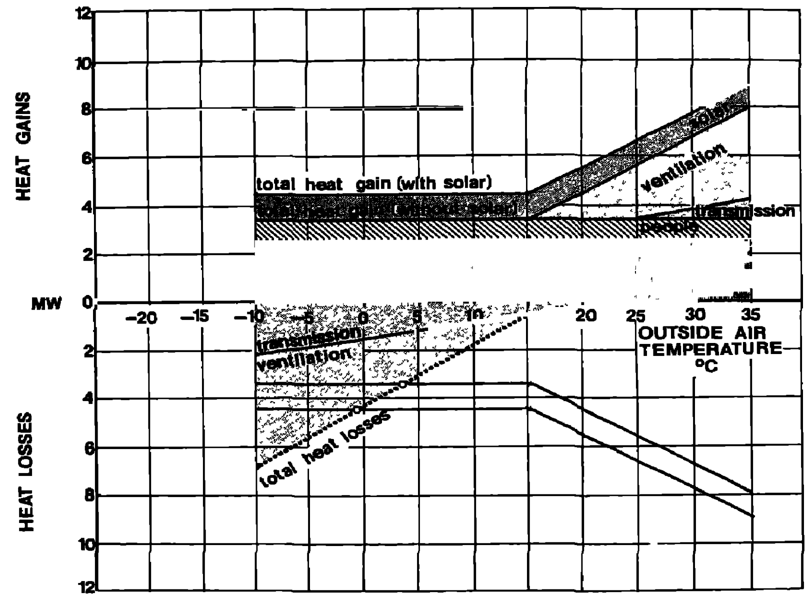

Figure 3.1 2-2
Heat load analysis of an office building in a relatively cold climate [8]

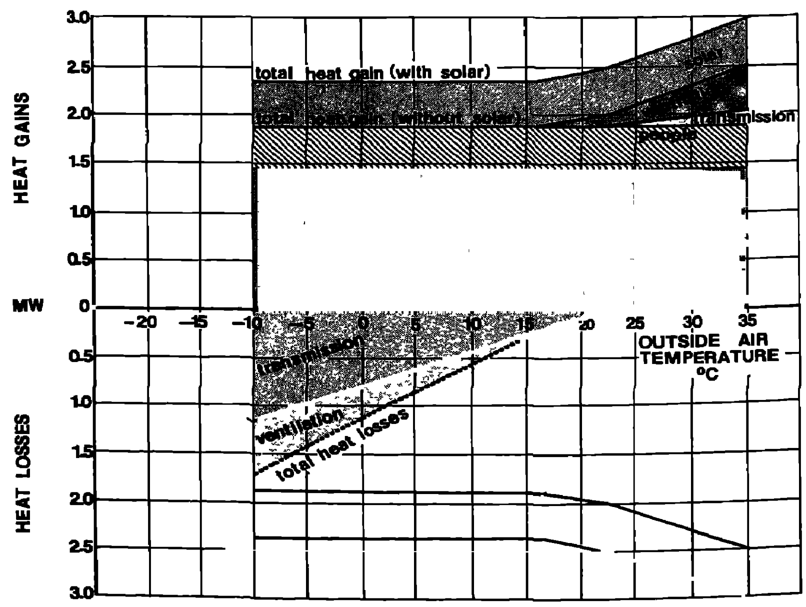

Figure 3.1.2-3
Heat load analysis of a government building.[9]

loads are higher The balance point is below the minimum winter design temperature.

Figure 3.1.2-4 represents an interesting load analysis of a school. Heat gains due to occupants are large, as are lighting loads Large heat losses are attributable to the ventilation air with very small heat gains from this same source. The reason is the location of the school in an area where summer average temperature is only 18°C.

Figure 3.1.2.-5 represents the large loads typical in a hospital located in warm climatic conditions. Huge ventilation loads provide significant opportunities for energy savings

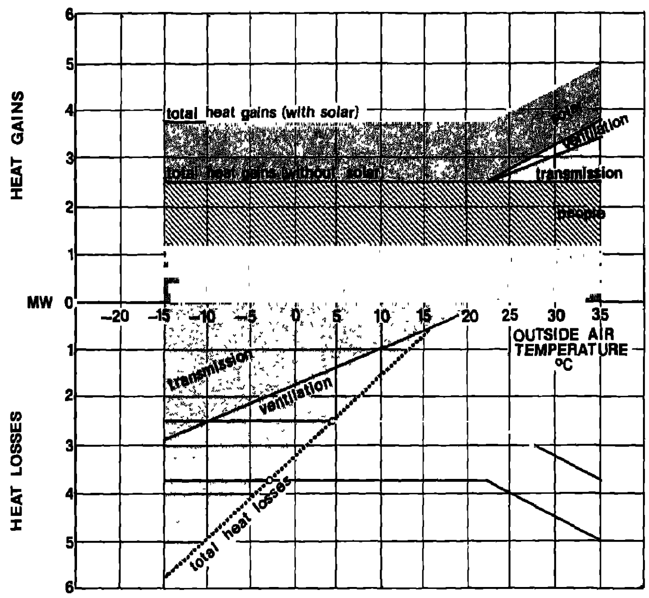

Figure 3.1.2-4
Heat load analysis of a school [10]

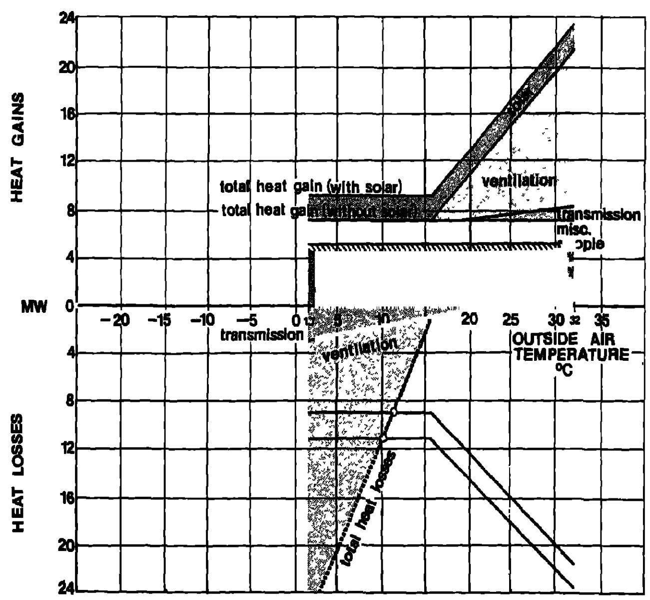

Figure 3.1.2-5
Heat load analysis of a hospital in a warm climate [11]

With the help of the graphs, Figures 3.1.2-6 and 3.1.3-7, we may conclude that a building whose theoretical heat balance temperature is higher than the mean annual temperature for that city probably presents few opportunities for energy savings through heat recovery. On the other hand, a heat balance temperature below the design winter temperature presents possibilities for heat reclamation. Outside air can be utilized to offset heat gains and thereby free cooling can be achieved. Heat recovery from exhaust air is also a possibility and heat rejected by refrigerating equipment is another potential source for reclamation.

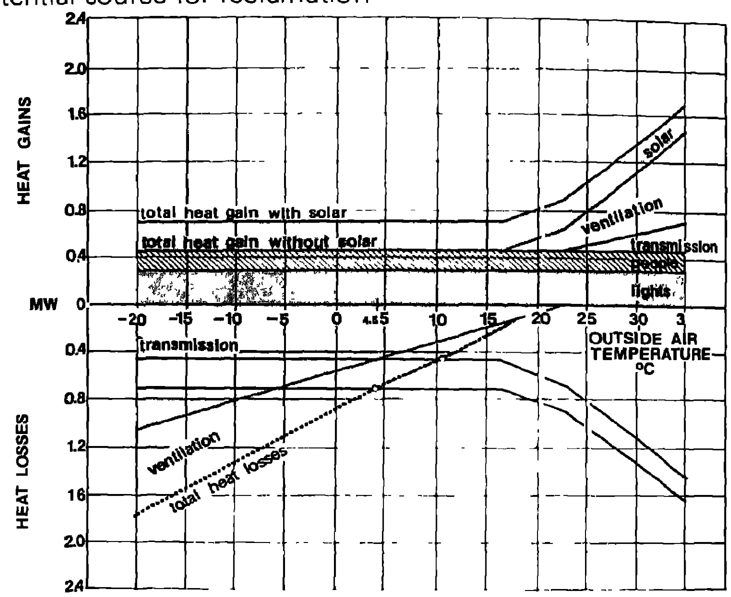

Figure 3.1.2-6
Heat load analysis of building with theoretical heat balance temperature higher than mean annual temperature.

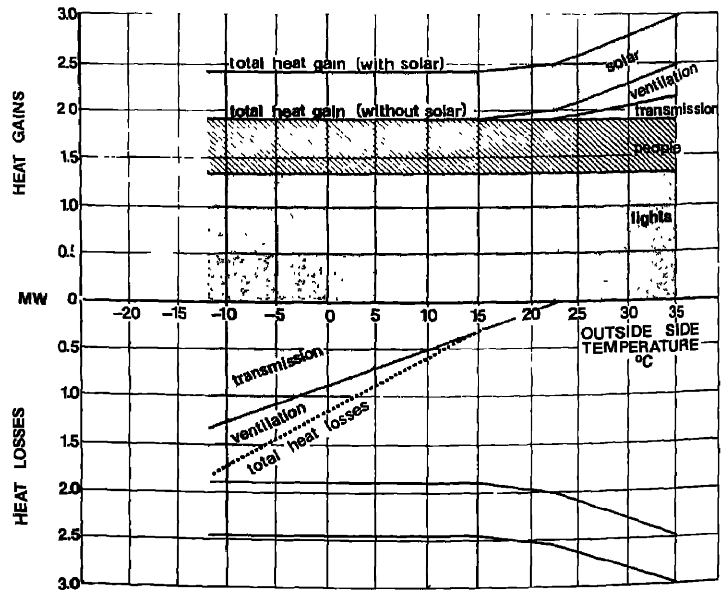

Figure 3.1.2-7
Heat load analysis of a building with theoretical heat balance temperature below design winter temperature.[13]

3.1.2.4 Computerized Analysis

It might be pointed out that the objective should be to design an energy conserving building and not just a thermally efficient one which is extremely well insulated and thus has a high resistance to heat flow

Over the last several years, computer programs have been developed to analyze building energy requirements through a full year of typical weather and operating conditions. Energy savings can be explored at the building design stage by simply conducting various alternative load analyses. This will determine the optimum combination of building shape, orientation, type of glazing, glass to wall ratio, building construction and insulation materials, lighting levels, lighting and ceiling systems etc The computer program could help the designer to calculate economically the building energy needs by simulating the performance of a specific building model with various characteristics and systems, under typical weather and operating conditions for a particular location

3.1.3 Heat Transmission[14]

Heat flows from one point to another whenever a temperature difference exists between the two points, the direction of flow is always towards the lower temperature

Water vapour also flows from one point to another whenever a difference in vapour pressure exists between the two points, the direction of flow is towards the point of low vapour pressure.

The rate at which the heat or water vapour will flow varies with the resistance to flow between the two points in the material

3.1.3.1 Heat Transmission Rate[15]

The heat transfer rate under steady state conditions, for a given part under standard conditions is a specific value referred to as the 'overall coefficient of heat transmission' or 'thermal conductance' or '*U* factor' *U* factor is the thermal transmission in unit time through unit area of a particular body or assembly including its boundary film (air film), divided by the difference between the environmental temperatures on either side of the body or assembly

3.1.3.2 '*Uo*' Concept

Since energy conservation is of prime concern with new building design, requirements are often stated in terms of '*Uo*' generally recognized as the combined thermal conductance of the respective areas of gross exterior wall, roof/ceiling, and floor assemblies

The '*Uo*' equation for a wall is as follows [16]

$Uo = U$ wall $\times A$ wall $+ U$ window $\times A$ window $+ U$ door $\times A$ door

where

Ao = the gross Ao area of exterior walls, m^2

U wall = U factor for opaque walls, SI units

A wall = opaque wall area, m^2

3.1.3.3 Heat Flow Through Building Structure

Heat gain through exterior construction (walls and roof) is normally calculated at the time of greatest heat flow. It is caused by solar heat being absorbed at the exterior surface and by the temperature difference between the outdoor and indoor air Both heat sources are highly variable throughout any one day and, therefore, result in unsteady heat flow through the exterior construction. This unsteady state flow is difficult to evaluate for each individual situation; however it can be handled best by means of an equivalent temperature difference across the structure.

The equivalent temperature difference is that temperature difference which results in the total heat flow through the structure as caused by the variable solar radiation and outdoor temperature.[17] The equivalent temperature difference across the structure must take into account the different types of construction and exposure, time of day, location of the building (latitude), and design conditions The heat flow may then be calculated, using the steady state heat flow equation with the equivalent temperature difference

$q = UA \times T$

where

q = heat flow, W

U = heat transmission coefficient $\left(\text{Note } U = \frac{1}{RSI}\right)$

A = area, m^2

T = equivalent temperature difference, °C

3.1.3.4 Example

The process of transferring heat through a wall under indicated unsteady state conditions may be visualized by picturing a 300 mm brick wall sliced into ten 30 mm sections Assume that temperatures in each slice are all equal at the beginning, and that the indoor and outdoor temperatures remain constant

When the sun shines on this wall, most of the solar heat is absorbed in the first slice and its temperature rises above that of the outdoor air and the second slice, causing heat to flow to the outdoor air and also to the second slice The amount of heat flowing in either direction depends on the resistance to heat flow within the wall through the outdoor air film. The heat flow into the second slice, in turn, raises its temperature causing heat to flow into the third slice This process of absorbing heat and passing some on to the next slice continues through the wall to the last or 10th slice where the remaining heat is transferred to the inside by convection and radiation. For this particular wall when temperatures are 35°C outside and 21°C inside, it takes approximately 7 hours for solar heat to pass through the wall into the room. Because each slice must absorb some heat before passing it on, the magnitude of heat released to the inside space would be reduced to about 10% of that absorbed in the slice exposed to the sun.

The solar heat absorbed at each time interval by the outdoor surface of the wall throughout the day goes through this same process

A rise in outdoor temperature reduces the amount of absorbed solar heat going to the outdoors and thus more flows inwards through the wall material.

This same process occurs with any type of wall construction to a greater or lesser degree, depending on the resistance to heat flow through the wall and the thermal capacity of the wall. (Ref. Section 3.1.5)

3.1.4 Heat Bridge[18]

3.1.4.1 Heat Flow Through Panels Containing Metal

The transmittance of a panel which includes metal or other highly conductive material extending wholly or partly through insulation should, if possible, be determined by test in the guarded hot box. When a calculation is required, a good approximation can be made by a 'Zone Method'. This involves two separate computations—one for a chosen limited portion, Zone A (**Figure 3.1.4-1**) containing the highly conductive element, the other for the remaining portion of simpler construction, called Zone B. The two computations are then combined and the average transmittance per unit of overall area is calculated. The basic laws of heat transfer are applied, by adding area conductances of elements in parallel, and adding area resistances of elements in series.

The surface shape of Zone A is determined by the metal element For the metal 'Tee' (**Figure 3.1.4-1**), the Zone A surface is a strip of width *W*, centered on the 'Tee'. For a rod perpendicular to panel surfaces, it is a circle of diameter *W* The value of *W* is calculated from the following empirical equation

$$W = m + 2d$$

where

m = width or diameter of the metal heat path terminal (mm).
d = distance from panel surface to metal, mm The value of d should not be taken less than 12 mm for still air.

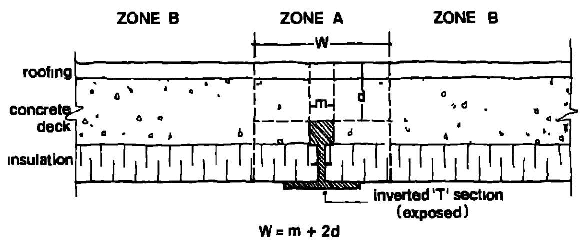

Figure 3 1 4-1
Heat bridge

3.1.4.2 Curtain Walls

Curtain wall constructions present a combination of metals and insulating materials. Few panels are true sandwich construction for which the thermal characteristics can be computed by combining the thermal resistances of the several layers Many panels have ribs and stiffeners which may create complicated heat flow paths for which it is virtually impossible to calculate the heat transfer co-efficients with reliability. Coefficients for the assembled sections must be determined on a representative sample by the guarded hot box method (ASTM designation C236).

3.1.4.3 Adjustment for Framing

Adjustment for parallel heat flow through framing and insulated areas may be made by using **Figure 3.1.4-1**.

Adjustment for the effect of framing should be applied after final *'Ui'* and *'Us'* values have been obtained for a given construction. In many cases this correction may be omitted.

$U_i = U$ value for area between framing members
$U_s = U$ value for area backed by framing members

Note: $U = \frac{1}{RSI}$

3.1.5 Thermal Capacity, Heat Storage and Pre-Cooling

The instantaneous heat gain and the actual load on the air conditioning equipment will rarely be equal, because of the thermal inertia or storage effect of
- —the building structures surrounding the conditioned space
- —the furniture, equipment and material stored within the conditioned space
- —any mass of solid or liquid material built-up within the space to artificially provide added thermal inertia

3.1.5.1 Thermal Capacity

The magnitude of the storage effect is determined largely by the thermal capacity of the materials surrounding the space It is limited by the amount of heat available for storage The specific heat capacity of a material is the amount of heat energy to be added to unit mass to change its temperature by one degree, J/(kg °C) Since the specific heat of most construction material is 0 83 kJ/kg °C, the thermal capacity of an enclosing structure is then directly proportional to the mass of the material used in its construction A typical steel building may have a mass of 250 kg/m² compared with 650 kg/m² for a typical concrete building so that the latter building would have over 2 5 times the thermal capacity of the former

SPECIFIC HEAT FOR COMMON MATERIAL	
Material	kJ/kg °C
Asbestos board with cement	0 84
Brick	0 92
Concrete (stone)	0 79
Gypsum plaster	0 84
Glass	0 84
Steel	0 50
Wood (average)	2 50

Table 3 1 5 1-T1
Specific heat for common material

The weight of material per unit floor area is usually established as follows

—Room or building exterior (one or more outside walls)

$$\frac{\text{(Weight of outside walls, kg)} + 0.5\ \text{(weight of partitions, floor and ceiling, kg)}}{\text{Floor area in room, m}^2}$$

—Room in building interior (no outside walls)·

$$\frac{0.5\ \text{(weight of partitions, floor and ceiling, kg)}}{\text{Floor area in room, m}^2}$$

—Entire building or zone

$$\frac{\text{(Weight of outside wall, partitions, floors, ceiling, structural members, kg)}}{\text{Air conditioned floor area, m}^2}$$

3.1.5.2 Storage of Heat in Building Structures[19]

The actual cooling load can be considered below the peak total instantaneous heat gain if the building structure is made to allow ample storage of heat. A smaller cooling load means smaller equipment to perform a specific job, in addition, the air quantities and/or water quantities are reduced, resulting in a smaller overall system. Also, if the equipment is operated somewhat longer during the peak load periods and/or the temperature in the space is allowed to rise a few degrees at the peak periods during cooling operation, a further reduction in required capacity results

The instantaneous heat gain within a typical occupied space is created by sun, lights, people, transmission through walls, roof and glass, infiltration and ventilation air and, in some cases, machinery, appliances, electric calculating machines, etc [20] A large portion of this heat gain is radiant heat which does not become an instantaneous load on the equipment, because it must strike a solid surface and be absorbed by this surface before becoming a load on the equipment The breakdown of the various instantaneous heat gains into radiant heat and convective heat is approximately as follows:

INSTANTANEOUS HEAT GAIN		
Heat gain source	Radiant Heat	Convective Heat
Solar without inside blinds	100%	—
Solar with inside blinds	58%	42%
Fluorescent lights	50%	50%
Incandescent lights	80%	20%
People*	40%	20%
Transmission	60%	40%
Infiltration/Ventilation	—	100%
Machinery/appliances	20%-80%	80%-20%
*Remaining 40% is dissipated as latent load		

Table 3 1 5 2-T$_1$
Breakdown of instantaneous heat gain into radiant and convective heat

As the radiant heat from the sources shown above strikes a solid surface (walls, roof, floor, ceiling, furniture etc.), it is absorbed, raising the temperature at the surface of the material above that inside the material and the air adjacent to the surface. This temperature difference causes heat flow into the material by conduction and into the air by convection The heat conducted away from the surface is stored, and the heat convected from the surface becomes an instantaneous cooling load The portion of radiant heat being stored depends on the ratio of the resistance to heat flow into the material and the resistance to heat flow into the air film With most construction materials, the resistance to heat flow, into the material is much lower than the air resistance; therefore, most of the radiant heat will be stored However, as this process of absorbing radiant heat continues, the material becomes warmer and less capable of storing more heat.

3.1.5.3 Solar Heat with Constant Space Temperature[21]

The highly varying and relatively sharp peak of the instantaneous solar heat gain results in a large part of it being stored at the time of peak solar heat gain as illustrated in **Figure 3.1.5-1**.

The upper curve in **Figure 3.1.5-1** is typical of the solar heat gain

for a west exposure, and the lower curve is the actual cooling load that results in an average construction application with the space temperature held constant. The reduction in the peak heat gain in this particular case is approximately 40% and the peak load lags the peak heat gain by approximately one hour.

The shaded areas represent the heat stored and the stored heat removed from the construction. Since all of the heat coming into a space must be removed, these two areas are equal.

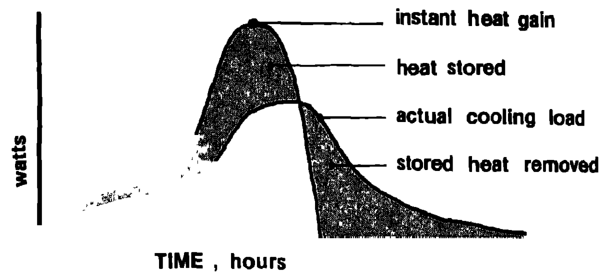

Figure 3.1.5-1
Solar heat gain, west exposure, average construction

3.1.5.4 Heat from Lights with Constant Space Temperature

The relatively constant light load results in a large portion being stored just after the lights are turned on, with a decreasing amount being stored the longer the lights are on, as illustrated in Figure 3.1.5.2. The upper and lower curves represent the instantaneous heat gain and actual cooling load from fluorescent lights with a constant space temperature The shaded areas are the heat stored and stored heat removed from the construction. The dotted line indicates the actual cooling load for the first day if the lights are on longer than the period shown

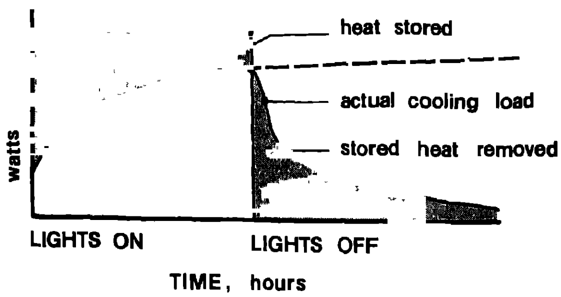

Figure 3.1.5-2
Effect of lights on cooling load

3.1.5.5 Influence of Thermal Capacity

Figures 3.1.5-1 and 3.1.5-2 illustrate the relationship between the instantaneous heat gain and the actual cooling load in average construction spaces. With light construction, less heat is stored at the peak (less storage or thermal capacity available), and with heavy construction, more heat is stored at the peak (more storage or thermal capacity available), as shown in Figure 3.1.5-3. This aspect affects the extent of zoning required in the design of a system for a given building; the lighter the building construction, the more attention should be given to zoning.

One more item that significantly affects the storage of heat is the operating period of the air conditioning equipment. All of the curves shown in **Figures 3.1.5-1, 3.1.5-2** and **3.1.5-3** illustrate the actual cooling load for 24 hours operation. If the equipment is shut down after 16 hours of operation, some of the stored heat remains in the building construction. This heat must be removed ('heat in' must equal 'heat out') and will appear as a pull down load when the equipment is turned on the next day, as illustrated in **Figure 3.1.5-4.**

Adding the pulldown load to the cooling load for that day results in the actual cooling load for 16 hours operation as illustrated in **Figure 3.1.5-5.**

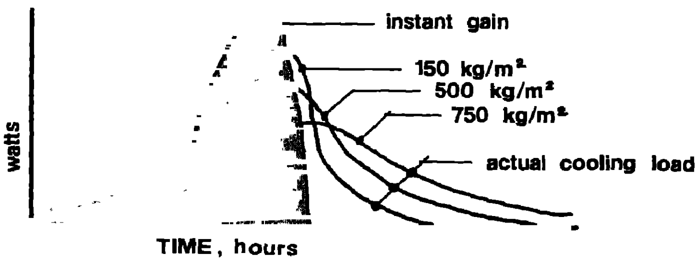

Figure 3.1.5-3
Cooling load of various types of construction

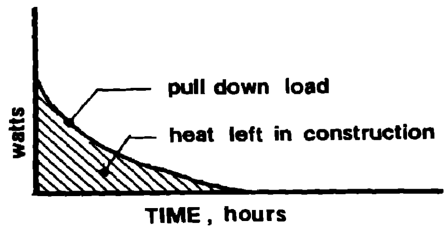

Figure 3 1.5-4
Pull down load

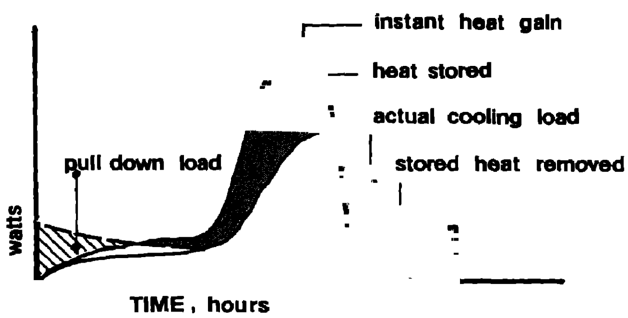

Figure 3.1.5-5
Actual cooling load.

3.1.5.6 Space Temperature Swing

In addition to the storage of radiant heat with a constant room temperature, heat is stored in the building structure when the space temperature is forced to swing. If the cooling capacity supplied to the space matches the cooling load, the temperature in the space remains constant throughout the operating period. On the other hand, if the cooling capacity supplied to the space is lower than the actual cooling load at any point, the temperature in the space will rise As the space temperature increases, less heat is convected from the surface and more radiant heat is stored in the structure

It must be observed that when a system is designed for a temperature swing, the maximum swing occurs only at the peak on design days, which are defined as those days when all loads simultaneously peak Under normal operating conditions, the temperature remains constant or close to constant

3.1.5.7 Precooling as a Means of Increasing Heat Storage

Precooling a space below the temperature normally desired increases the storage of heat at the time of peak load only when the precooling temperature is maintained at the control point This is because the potential temperature swing is increased, thus adding to the amount of heat stored at the time of peak load. Where the space is precooled to a lower temperature and the control point is reset upward to a comfortable condition when the occupants arrive, no additional storage occurs In this situation, the cooling unit shuts off and there is no cooling during the period of warming up When the cooling unit begins to supply cooling again, the cooling load is approximately up to the point it would have been without any precooling.

Precooling is very useful in reducing the cooling load in applications such as churches, supermarkets, convention-hall, banquet room, theaters, etc , where the precooled temperature can be maintained as the control point and the temperature swing increased to 4°C or 6°C

3.1.5.8 Related Reading Elsewhere in the Handbook

The electrical power savings which can accrue from energy storage systems, in addition to building mass, are discussed in **Section 3.4.3.** The reader is also referred to an examination of waste heat recovery including heat-of-light recovery, contained in **Section 3.13.**

3.1.6 Thermal Movement

This subject is discussed here with reference to HVAC systems The reader is also referred to **Section 3.3** Building Physics and **Section 3.3.4** Stack Effect

3.1.6.1 Thermal Movement Due to Stack Effect

Stack effect has important consequences for tall buildings and is described in detail in **Section 3.3.4.**

3.1.6.2
Stratification of Heat[22]

There are generally two situations where heat is stratified and will reduce the cooling load on the air conditioning equipment
—Heat may be stratified in rooms with high ceilings where air is exhausted through the roof or ceiling
—Heat may be contained above suspended ceilings with recessed lighting and/or ceiling plenum return systems.

.1 **Heat Stratification in Rooms with High Ceilings:** The first situation generally applies to industrial applications, churches, auditoria, and the like The second situation applies to applications such as office buildings, hotels, and apartments With both cases, the basic fact that hot air tends to rise makes it possible to stratify loads such as convection from the roof, convection from lights, and convection from the upper part of the walls. The convective portion of the roof load is about 25% (the rest is radiation); the light load is about 50% with fluorescent (20% with incandescent), and the wall transmission load about 40%

In any room with a high ceiling, a large part of the convection load being released above the supply air stream will stratify at the ceiling or roof level Some will be induced into the supply air stream Normally, about 80% is stratified and 20% induced in the supply air. If the air is exhausted through the ceiling or roof, this convection load released above the supply air may be subtracted from the air conditioning load This results in a large reduction in load if the air is to be exhausted. It is not normally practical or desirable to exhaust more air than necessary, as it must be made up by bringing outdoor air through the apparatus—which usually results in a larger increase in load than the reduction realized by exhausting the air.

Nominally, about a 5°C to 10°C rise in exhaust air temperature may be figured as load reduction if there is enough heat released by convection above the supply air stream

Hot air stratifies at the ceiling even with no exhaust but rapidly builds up in temperature, and no reduction in load should be taken into account where air is not exhausted through the ceiling or roof.

.2 **Heat above Suspended Ceilings:** With suspended ceilings, some of the convective heat from recessed lights flows into the plenum space Also, the radiant heat within the room (sun, lights, people, etc.) striking the ceiling warms it up and causes heat to flow into the plenum space These sources of heat increase the temperature of air in the plenum space which causes heat to flow into the underside of the floor structure above When the ceiling plenum is used as a return air system, some of the return air flows through and over the light fixture, carrying more of the convective heat into the plenum space.

Contained heat within the ceiling plenum space tends to 'flatten' both the room and equipment load

3.1.7
Protective Measures Against Heat Gain

It was observed previously that heat gains, and therefore building cooling loads are influenced by.
—heat transfer through the building envelope
—introduction of ventilation air and/or infiltration
—internal heat generated by the lights, equipment, and people within the building.

The size, function, and number of hours the building is meant to be operated have a significant influence on the relative magnitude of each of these energy components The load in highrise commercial buildings and retail establishments is due primarily to internal loads and ventilation requirements On the other hand, suburban low-rise plants and offices tend to be strongly influenced by environmental factors which control heat gain through the building envelope and by infiltration It must therefore be recognized that all buildings are different and their individual physical and operational characteristics result in varying energy requirements

3.1.7.1 Architectural Design for Energy Conservation

This subject is covered in a number of **Sections** in the Handbook, particularly **4.0** Design Criteria for New Construction and **4.9** Protective Elements

3.1.7.2 Air Conditioning Systems

Proper importance and due considerations should be given to the appropriate type of air conditioning system for the building, right at the design stage The space requirements for the mechanical equipment and distribution system must be considered before the schematic designs are completed by the architects The criteria for the building shape, orientation, amount of window area, type of glazing, shading devices, etc should be developed simultaneously with due concern towards the type of air conditioning systems required to minimize energy consumption

Additional measures may be taken to minimize air conditioning requirements for all non functional and non full-time areas, e.g. store rooms, corridors, lobbies, exit, stairs, toilets etc and by grouping them together All process areas, if any, in a building should be grouped together and physically separated as far as possible from the main office building in order to avoid unnecessary imbalance and loss of energy.

The protection and correct location of the air conditioning condensers is important If located in direct sunlight, they are affected by solar heat and their effectiveness is decreased To combat this, where possible, they should be located on the north side of the building and if at ground level they should be shaded by shrubs or a sun shield Roof-top units should also be protected by sun shields wherever possible

3.1.7.3 Reducing Solar Heat Gain[23]

Reference has already been made to the significant extra load which can be placed on air conditioning systems by solar gain through windows if measures are not taken to control it However, in many buildings, the roof and not the windows constitutes the largest source of heat gain.

3.1.7.4 Reducing Internal Heat Gain[24]

From the previous discussion in **Section 3.1.1**, it is obvious that internal heat gain requires serious consideration. Its potential sources have already been identified and the designer should ensure that they do not add to the energy requirements of the building

Some of the basic solutions would be as follows.

—Isolate motors and heat generating equipment into a non-conditioned space where outdoor make-up air can be used for ventilating purpose

—Exhaust heat locally at the source whenever enthalpy of outdoor make-up air is lower than the enthalpy of the space.

—Insulate tanks and piping or isolate into a non-conditioned but ventilated space as above.

—Plan to use the space more wisely to avoid unnecessary lighting levels Lower lighting fixture wherever possible to reduce the lighting load. Consolidate personnel to a given area and thus reduce the total area to be air conditioned.

—Minimize air exhaust from conditioned space Make sure that the amount of air being exhausted from the conditioned space to the atmosphere is being kept to an absolute minimum. Make-up air for laboratory, kitchen, shower rooms, washroom and change room exhaust requirements should be provided from a source other than the conditioned space such as from an adjacent non-conditioned space or from outdoors. Such areas should be grouped accordingly

3.2 Heat Loss

3.2.1 Heat Loss Replacement

Heat lost from a building must be replaced in order to maintain a constant temperature otherwise the temperature of materials and air within the building envelope decreases In such circumstances heat will flow, by conduction, through the building enclosure and towards the lower temperature A temperature difference is required for heat flow to occur, consequently there is no heat loss from rooms, within a building, where adjacent spaces are the same temperature as the room.

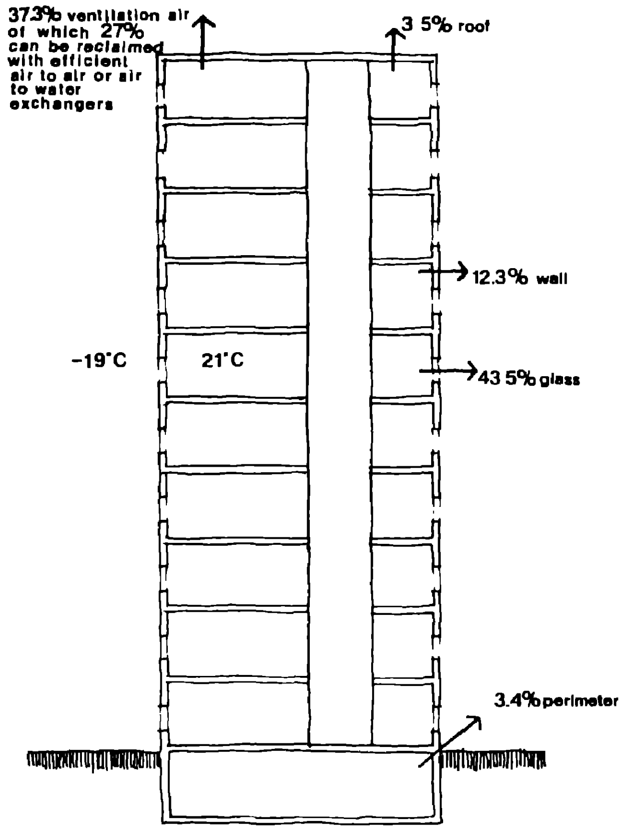

Figure 3 2 1-1
Heat loss of office building

One of the primary purposes of identifying the heat loss and its various components is to assist in optimizing the cost effectiveness of the building envelope as it relates to energy consumption This necessitates an analysis of glass area, insulation values and ventilation/infiltration control It is generally accepted that heat loss and the resultant energy required to replace this loss within the structure is in the order of 25% of the total energy requirement for the building. This of course could be significantly greater or less for a specific project

3.2.1.1 Internal Heat Energy

Heating, ventilation and cooling systems must be designed and controlled in a manner that will fully utilize all heat energy in a building. This heat results from operation of lights and equipment, passive solar gains, and metabolism of people. This heat can be

absorbed by outside air introduced 5°C to 10°C below room temperature

Outside air introduced into a building is lost or removed through exfiltration and exhaust. Up to 80% of the heat required to heat outside air, replacing exhaust, can be recovered from exhaust air This recovery process cools exhaust to near outside temperature and heats incoming air to near room temperature. Care must be exercised to avoid frosting or freeze up on the heat exchange surfaces of the air to air heat exchangers, this can occur if incoming outside air is cold and contains a large amount of moisture

Heat required for ventilation air can be up to 50% of the heating required for buildings so that heat recovery from exhaust can reduce the total building heating requirement by up to 40% Heat recovery equipment has a beneficial effect during cooling operation, but to a much lesser degree Energy requirements for cooling are due to a large extent to the heat generated within the building

3.2.1.2 Heat Balance

Calculation and use of the heat balance temperature is an important part of energy efficient building design The heat balance temperature is the outside temperature at which heat lost from a building equals the heat generated within the building This balance temperature should by design decisions be established as low as is practical so that ambient temperatures lower than the balance temperature occur for a small percentage of the year A balance temperature of − 10°C is appropriate for locations where winter outside design temperatures are between − 20°C to − 35°C.

3.2.1.3 Related Reading Elsewhere in the Handbook

Heat loss relates to other sections of this Handbook and reference should be made to the following

(1) Section 3.9 for determination of heating requirements for ventilation
(2) Section 3.10 Solar Energy and 3.11 District Heating Quantitative heat losses are required for application of data in these sections.
(3) Section 4 5 Energy Efficient Design Criteria.
(4) Section 5.0 Thermal Upgrading of Existing Constructions and 'Built-in' Energy Systems.
(5) Section 6.0 Urban Planning and Development Criteria

Definitions of Thermal Conductivity and Thermal Resistance, as they relate to building materials, will be found in Sections 3.6.2, 3.

3.2.2 Heat Loss Through Walls, Floors, Roofs, Doors and Windows

Resistance to heat flow is stated by the unit *RSI* m² C°/W
The rate of heat flow is the reciprocal of the resistance. It is also directly proportional to the temperature difference from one side of the component, or assembly, to the other. The formula for calculating heat flow (heat loss) is:

Area × Reciprocal of *RSI* × Temperature difference. By inserting units into this formula, we obtain the following:

$$m^2\ (W/m^2\cdot{}^\circ C)\ \Delta t\ {}^\circ C = W$$

3.2 Heat Loss

The *RSI* of a wall, floor or roof is the total of *RSI* values for each material in the assembly. This includes both outside and inside air films.

The *RSI* of manufactured components such as doors, windows and curtain walls should be assessed by the designer prior to their selection.

Wind has a minimal effect on total *RSI*. Air film *RSI* is reduced as wind velocity or air movement increases at the surface of the building enclosure. The *RSI* difference between still air and 24 km/h air motion is 0.1. Wind can have a dramatic effect on infiltration; however, strictly speaking, this falls into a different category from heat loss and is subject to a separate analysis.

The first step in determining the heat transmission loss through a wall, roof or floor is to establish the *RSI*.

3.2.2.1 Example: Wall *RSI* Calculation

An example of a typical wall *RSI* calculation is as follows:

(1)	Exterior Air Film (24 km/h wind)	
(2)	Face Brick (100 mm)	— 0.08
(3)	Cavity Air Space (20 mm)	— 0.12
(4)	Insulation (75 mm)	— 2.55
(5)	Concrete Block (150 mm)	— 0.16
(6)	Gypsum Board (13 mm)	— 0.08
(7)	Interior Air Film (Still Air)	— 0.12
	TOTAL *RSI*	3.14

The ASHRAE Handbook of Fundamentals[1] should be consulted to obtain *R* or *RSI* values for various building materials. Where resistance *R* is stated in Imperial units, this can be converted to *RSI* by using the formula $0.176R = RSI$.

Doors on a small building such as a single family residence can create a significant heat loss. The heat loss through hollow wood or steel doors is similar to double glass, for an equivalent area. Insulated doors will reduce this heat loss and *RSI* values can be obtained from manufacturers.

The transmission heat loss for a typical building can be calculated as follows:

Heat Loss

ROOF	$—A \times 1/RSI \times \Delta t$ °C = watts
WALLS	$—A \times 1/RSI \times \Delta t$ °C = watts
GLASS	$—A \times 1/RSI \times \Delta t$ °C = watts
DOORS	$—A \times 1/RSI \times \Delta t$ °C = watts
	TOTAL HEAT LOSS = watts

Where:

A = Area in square metres
$1/RSI$ = Rate of heat flow in watts per °C per square metre
Δt °C = Temperature difference between outside design temperature and interior design temperature.

The heat loss due to ventilation and/or infiltration is added to the total transmission heat loss in order to establish the total heating requirement for a building. Refer to Section 3.9 for recommended ventilation rates.

In those cases where there is a reliable heat generating component in a building (such as lights, occupants, etc.) this can be considered as an important potential contributing to the heat input required (Ref Section 3.1)

3.2.2.2 Example: Heat Loss Calculation

Given

—Design Temperature – 29°C outside, 21°C inside, 20% *RH*
—10 storey office building
—Floor to floor dimension 3 5 m
—Typical floor 30 m × 30 m
—Glass area 25% double glass
—Wall and roof *RSI* = 3 5 W
—Ventilation rate 25 L/s m²
—Area occupancy per person 10 m²
—Lights 20 W/m²
—Heat gain per person 73 5 W

Basic Data	Roof area	30 × 30 =	900 m²
	Wall—gross area	4 × 30 × 3.5 × 10 =	4 200 m²
	—glass area	4200 × 25 =	1 050 m²
	Wall net area	=	3 150 m²
	Gross floor area	10 × 30 × 30 =	9 000 m²
Heat Loss	Roof	900 × 1/3.5 × 50 =	12 857 W
	Wall	3150 × 1/0 33 × 50 =	45 000 W
	Glass	1050 × 1/0 33 × 50 =	159 090 W
	Total heat loss		216 947 W
	Outside air heating	900 × 0 25 × 1 21 × 50 =	136 125 W
	Total heat loss and outside air heating	=	353 072 W
Heat Gain	Heat from lights	=	180 000 W
	75% Exhaust air heat recovery	=	102 094 W
	People	$\frac{900 \times 10}{10} \times 73.5$ W =	66 176 W
	Solar gain—(South)	=	77 205 W
		Total heat gain =	425 475 W
Net Heat Gain			72 403 W

When all of the above factors are in effect, the internal heat gains and heat recovery exceeds the heating energy required It is important to ensure that the available heating capacity is sufficient to heat the structure when all of the internal gains listed are inoperative This will occur during unoccupied night time hours

3.2.2.3 Effect of Orientation

Orientation of buildings has important effects on net heat loss. Prevailing winds and effect of the sun are the two predominant factors. Buildings should be located to avoid structure surfaces that are perpendicular to the prevailing wind direction. Entrances and significant window openings should be avoided on surfaces that are at right angles to the normal wind position. Where possible the structure should be oriented to cause equal deflection of the

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The *RSI* of a wall, floor or roof is the total of *RSI* values for each material in the assembly. This includes both outside and inside air films.

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TOTAL *RSI*	3 14

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TOTAL HEAT LOSS = watts

Where·

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wind stream so as to reduce the positive pressure effect on a surface which will cause exfiltration on the leeward side of the structure

Sun effects on residential buildings in particular can be utilized to a significant degree by the thoughtful designer Passive solar heating in the south facing areas of residences can be realized through correct orientation Because of the change in sun angle in winter versus summer, the disadvantages of overheating in warmer months can be greatly reduced by the proper use of shading devices. These can be roof overhangs, balconies, awnings, trees, etc. (Ref., **Section** 4.9 Protective Elements) Critical comfort zones in residences therefore should be located on south exposures.

3.2.2.4 Internal Heat Generation

It is common for heat generated within a building to exceed heat loss, during cold weather, for the majority of the occupied period in well designed office buildings and schools (Ref Section 3) Many commercial retail spaces generate a surplus of energy i.e. heat during all occupied periods regardless of outside conditions. Large buildings because of the ratio of skin to floor area produce relatively greater quantities of heat The usual method of controlling temperature in this case is to increase the ventilation rate so that excess heat is absorbed **Figure** 3.2.1-1

3.2.3 Humidification and Dehumidification

Relative humidity is the percentage value of the amount of moisture in an air volume versus the amount of moisture the same air volume would contain if it were completely saturated. The relative humidity or the amount of moisture contained in any given volume has important effects not only on the human occupants, but on the structure as well Generally, if ventilation rates can be maintained to a minimum required for a closed building namely 5 L/s of dry air per person no additional moisture need be added Under these conditions the space will achieve a humidity level of approximately 20% This is because under sedentary conditions the latent moisture contributed to the space from an individual is 0.025 mLs

Relative humidity is affected inversely with the temperature of the air and therefore, for a given air volume decreases as the temperature increases and increases as the temperature of the air decreases. All operations for changing the state of an air stream are energy intensive. It is essential therefore, to maintain only those relative humidity values which are commensurate with human comfort or artifact protection

Damage to structures can occur if humidity levels are greater than the skin of the building was designed to accept. Techniques such as thermal breaking of walls, fenestration and doors are essential to maintain adequate humidity levels in cold climates. Single, double, triple and even quadruple fenestration may be necessary to maintain essential high level humidity levels while avoiding condensation on the interior surfaces. See **Figure 3.2.3-1** for relative humidity values which will cause condensation to occur. **Figure** 3.2.3-2, metric Psychrometric Chart shows relative humidity values at given wet bulb and dry bulb temperatures.

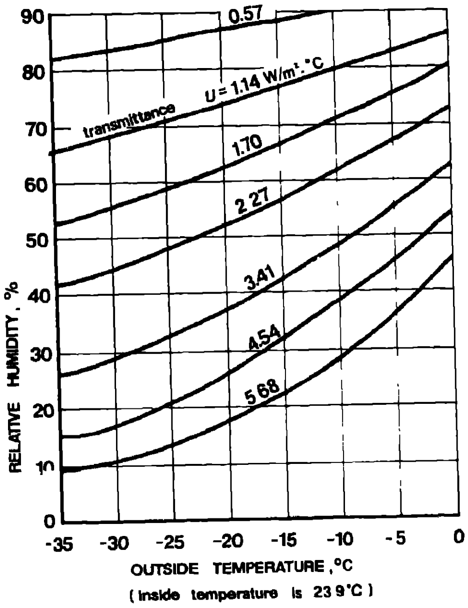

Figure 3.2.3-1
Humidity values and condensation

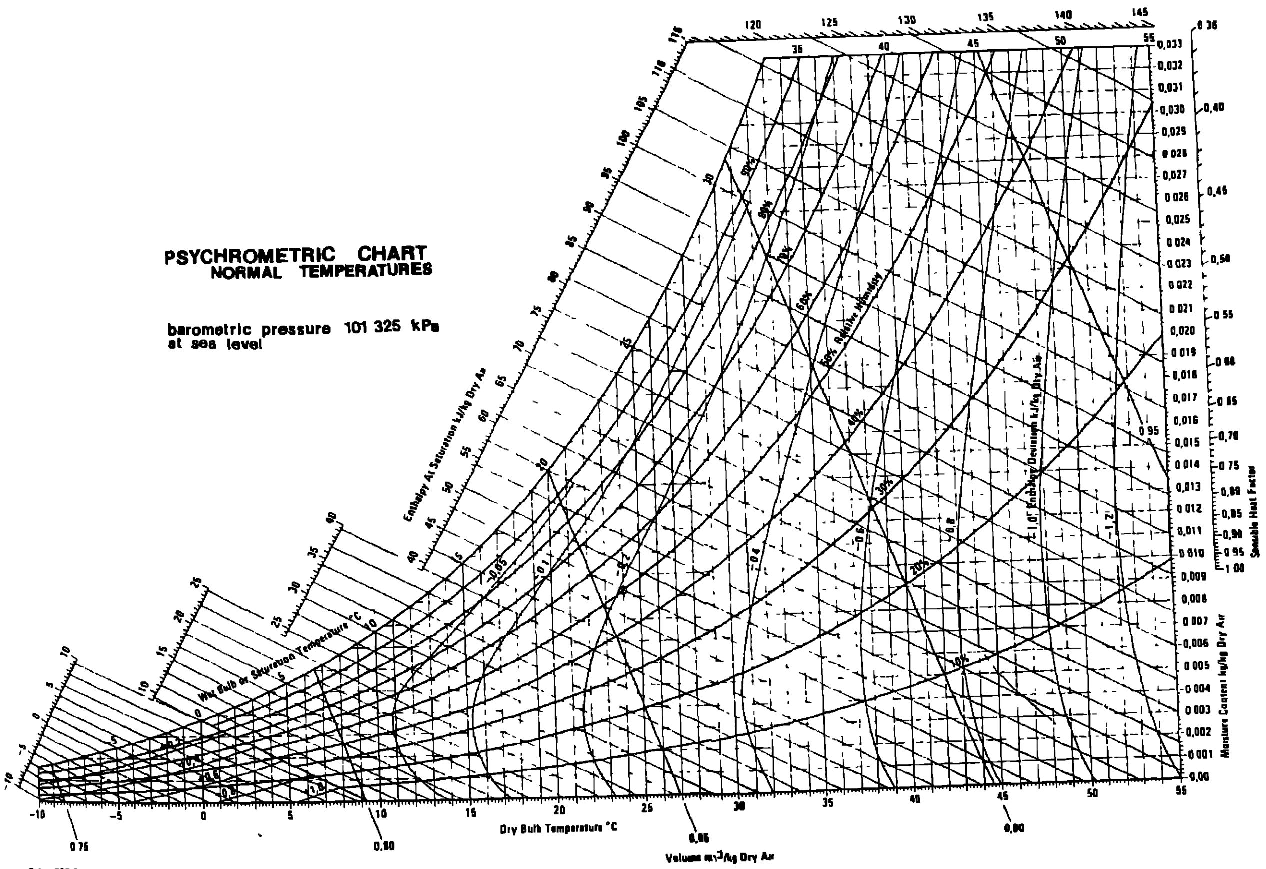

Figure 3.2.3-2
Psychrometric chart, normal temperatures
Reproduced by permission of Carrier Corporation
Copyright 1979, Carrier Corporation[2]

Dehumidification of an air volume is the process of removing moisture. This operation can be very energy intensive depending on the method employed There are three commonly used methods for decreasing moisture in a building, as follows

3.2.3.1 Introduction of Dry Outside Air

Generally the lowest energy consuming method of removing moisture, is that of introducing dry outside air through the building mechanical ventilation system If the air introduced is dryer than the space air, it will absorb moisture and reduce the relative humidity.

Cold outside air has a low moisture content However, heat must normally be added to it for occupant comfort prior to introduction into a space and this energy change dramatically increases its ability to absorb additional moisture

Quantitative amounts of outside air can therefore be introduced with enthalpy controls to vary the moisture levels within very close tolerances. Swimming pools and atria are two specific and common examples where the use of outside air is an economical method of space moisture control.

3.2.3.2 Mechanical Cooling

The second method of removing moisture involves mechanical cooling Mechanical refrigeration equipment is employed to reduce the temperature of the supply air stream to the space This process of cooling reduces the ability of the air to transport moisture and therefore it condenses on the cold surfaces of the heat exchange apparatus and is effectively removed from the space This method of moisture removal is the most common in use today and can be controlled to produce results to very close tolerances It is, however, an energy intensive method as the refrigeration process which cools the air stream to release moisture requires significant power The psychrometric process involved here is to cool the air stream below the dew point (i.e. the temperature at which condensation occurs) whereby quantitative amounts of moisture are removed

3.2.3.3 Moisture Absorbing Chemical

The third method of moisture removal is by use of moisture absorbing chemicals. Some chemicals by nature have an extreme affinity for water vapour. This property can be utilized in apparatus placed in the air stream which extracts moisture as the air passes through or over the chemical bed. These systems require a regenerative cycle during which the partially saturated chemicals are dried with heat energy and the moisture removed, normally to the outside, via a separate air stream This regenerative or drying process restores the moisture absorbing properties of the chemicals and is normally a continuous process.

3.2.3.4 Related Reading Elsewhere in the Handbook

Reference should also be made to Sections:

(1) 3.8 Heating and Cooling
(2) 3.9 Ventilation
(3) 4.5 General Criteria for Energy Efficient Design
(4) 5.0 Thermal Upgrading of Existing Construction and 'Built-in' Energy Systems.

3.2.4 Air Change

Air change is a method of expressing the rate of infiltration, ventilation or recirculation per unit of time. Air change per hour is the usual terminology used

Infiltration rates relate to crackage and ventilation rates relate to occupant density or floor area so that air change terminology is not particularly precise. Generally speaking, it should be limited to use when other, more precise, information is not available.

ACH or air change per hour implies the number of times the air or the cubic content of a given space is changed in one hour. This term is a misnomer; complete air change theoretically can never take place. Change of air in a room versus ventilation rate is exponential, the closest approximation is to change 99% of the air in a given space over a period of one hour. Although not precise in a strict design exercise, certain buildings or structures are often referred to as requiring from one to ½ ACH to 30 ACH as ventilation requirements. The former value might refer to a warehouse building with little or only intermittent human occupancy while the latter would refer to an emergency exhaust rate to expel dangerous concentration of chemicals or harmful fumes.

Air change per hour means, of course, that the air within the total volume of the space or structure at a certain energy content is being expelled from the building This air must be replaced with outside air at either a much lower energy content or possibly at a much higher energy level. Regardless of the temperature of the outside air, certain work must be expended to both transport and change its (thermal) energy level to produce the designed temperature condition in the structure *It is important therefore that the amount of ventilation or air change supplied be no more or no less than is required for the 'end use' of the structure, it should not be related to general rules of thumb, i e air changes per hour.*

As a corollary to this, the temperature to be maintained in the space should be the minimum that is satisfactory for the function and this temperature should be closely controlled. The expanded use of heat reclaim devices to extract energy from the air stream being expelled and transferring it to the new make up air is also vitally important

3.2.5 Cooling and Condensation

The psychrometric chart shows graphically relationships of temperature, humidity, water content and enthalpy of air. The dew-point of a specific temperature/relative humidity space condition can be determined graphically from this chart. For example, if a space air condition is 21°C and 50% relative humidity, the dewpoint is 10°C. This means that when this air is reduced in temperature to 10°C the relative humidity will become 100% and condensation will begin to occur. Should this air contact a surface or object that is 10°C or lower, condensation will occur on that surface. (See **Figure 3.2.3-1**).

It is sufficient, in cases where minimum humidity is maintained during the heating season, to place vapour barriers on the warm side of the insulation. In buildings such as art museums, where relative humidity is maintained at 50% continuously, it is necessary to calculate temperature gradient through the wall, in order to

establish that the vapour barrier is at a temperature above the vapour condensation point of the interior space air condition.

The most likely point of building condensation is the interior surface of glazing The interior air film is a significant part of the insulating value of the glass as the interior glass surface temperature is subsequently lower than room temperature Most of the air film is removed by forced air circulation across the glass, which increases the glass surface temperature and therefore raises the dewpoint. It should be noted that the removal of the air film will also increase the rate of heat loss through the glass This rate of heat loss increase will be approximately 25% for double glass and 15% for triple glass

Condensation and freezing of moisture will occur within insulation and other wall components if vapour barriers are not adequate or properly installed This is particularly critical in connection with buildings which have high internal humidity requirements such as hospitals, art galleries and museums Moisture that can migrate around the vapour barrier condenses as it reaches the dewpoint and freezes at 0°C. This process results in a decrease of insulating value, which moves the dewpoint closer to the interior surface of the wall, resulting in more frequent or extensive condensation Condensation of vapour results in lowering of the vapour pressure at that point and this encourages a continuation of vapour flow to the condensation point (Ref also Section 3.5 1)

A return to warm outside temperature results in the frost melting and water leaking out of the wall into other parts of the structure and elsewhere, with potentially damaging consequences

3.2.6 Thermography of Building

Thermography is a building science methodology which can be used to measure the degree of heat exchange between a building and its surroundings It is a valuable tool for locating, identifying and assessing deficiencies in building enclosure systems, when employed and interpreted by those with building science knowledge A recent paper[3] by Peter A D Mill, Public Works Canada, reviewed this subject in detail and provides the basis for the following discussion.

Appreciation of the importance for life-cycle cost of buildings compared to initial capital costs has renewed the importance of evaluating overall technical performance of building enclosure. Building science, a relatively new discipline within architecture, aims at achieving improved technical performance through better understanding of building enclosure as a series of complex and interacting phenomena. Building science reflects the fundamental laws of physics and chemistry and their effects on complex assemblies of materials Thermography is a tool that when used in conjunction with other building science methods, can be most effective in locating thermal inadequacies in building enclosures.

3.2.6.1 Evaluation of Building Performance

The special demands of the Canadian climate, coupled with the growing requirement for energy efficiency, provide an opportunity to develop building enclosures appropriate to our environment In order to do this, we must assess the actual performance of

existing buildings, develop greater ability to predict the probable performance of new ones and be aware of the consequences of poor retrofitting of existing buildings especially those of historic value

Emerging building science methodologies, such as thermography, offer the potential for quickly and economically identifying building enclosure defects and diagnosing their causes

The speed of thermal interpretation through thermography presents an opportunity for quicker evaluation of performance Consequently, thermography can speed up recommendations for future design guidelines. Although quantitative temperature measurement is possible using thermography, the accuracy is affected by

condensation
material roughness
air pollutants
reflected radiation
angle of sight
precipitation

All given factors influence the actual value of a material's emittance and must be taken into account to obtain accurate readings of temperature variation

While there are other techniques for measuring temperature variation on a material's surface, thermography has been proven to have certain advantages It allows large surfaces to be examined easily and quickly Measurements can be taken at considerable distances from only one vantage point In addition to qualitative temperature assessment, quantifiable measurements are achievable if certain controls are established Because thermographic data can be interpreted to assess performance, the technique can be used to interpret the energy implications of different types of wall construction Although the common types of construction defects (omitted insulation and air leakage) are not easily detected by visual inspection, they can be detected readily using thermography

Poor technical performance in buildings is common and it is increasing life-cycle costs Recent investigations have revealed that defects in insulation placement, air tightness, and vapour control are common They are often severe, and cause high operating and maintenance costs These inadequacies result in moisture accumulation on inside surfaces of walls and roof constructions (Refer to Section 3.2.5) This reduces thermal effectiveness, and in certain instances, eventually causes material degradation. The immediate effects of these faults can be complaints about water leaks, and increased costs of heating and cooling In the long term, increased maintenance will be required

3.2.6.2 Identification of Thermal Problems

Field and aerial applications verify laboratory conclusions that thermographic analysis is capable of identifying thermal problems. Aerial tests show that buildings with thermal problems can be identified easily and put into a priority listing for subsequent ground evaluations This approach is quicker and more efficient than any other approach now being used for assessment of building enclosure performance.

The potential evaluatory roles of thermography within the building industry includes:

- —energy-efficiency assessment of existing buildings by interpreting heat-flux distribution
- —quality assurance of new buildings by identifying and interpreting thermal inadequacies
- —preventive maintenance assessment
- —research and teaching mechanism to improve building science knowledge and expertise.

3.2.6.3 Teaching Tool

Thermography is used to make a holistic and instantaneous estimation of various surface temperatures. These temperatures are proportional to the degree of heat exchange between a material and its surrounding environments.

Thermography has also proven useful in the teaching of those thermal principles which dictate building enclosure performance to maintenance and design personnel. Because the technology allows one to see a thermal anomaly in any construction, it also allows the observer, if building science techniques are used concurrently, to interpret the significance of the anomaly to a building's performance This presents unique opportunities for understanding an element's performance and gaining an appreciation of the holistic performance of any building form. Previously this skill relied on time-consuming training (five years) for which most field personnel do not have the time or the training opportunities.

Infiltration requires serious attention in building design and construction. It is not unusual for heating requirements resulting from infiltration to approximate or exceed those required as a result of transmission heat losses

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Air movement into and out of a building is caused by wind pressure and stack effect. These factors convert to air pressure which cause air leakage through cracks in building construction.

Air infiltration caused by wind pressure enters the building on the windward side, travels across the building and exits on the leeward side where a negative pressure occurs due to air deflection over and around the building.

Air infiltration caused by stack effect in cold weather enters the building in the lower half of the building and exfiltrates in the upper half of the building This phenomena causes air to move vertically through the building The main routes of air movement are through elevator shafts and stairwells

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The air tightness of a building, particularly a high building, but also in new residential design, requires considerable care in both architectural detailing and in construction It is possible to design and construct a building with a negligible amount of infiltration This can be achieved in residential building by paying particular attention to types of interior wall finishes, weatherstripping of windows and doors and the provision of vestibules. The problem becomes much more complex in high-rise buildings but care in proper sealing of joints and use of revolving doors and vestibules on entrances will reduce infiltration and the resultant waste of energy required to treat this undesirable air mass. Lack of adequate consideration of this subject will usually result in a building with excessive infiltration and heating problems.

Considerable progress has been, and is being, made in minimizing infiltration in single family residential buildings. In order that sufficient air be provided for combustion of fossil fuels, air intakes with controls should be provided.

Vapour levels tend to build up to unacceptable levels in buildings that are tightly sealed and the situation can be aggrevated in those that are heated without combustion. This situation can be controlled by mechanical ventilation

It may seem that efforts to reduce infiltration in dwellings are voided by the necessity of mechanical ventilation, making infiltration reduction efforts useless This is not the case Mechanical ventilation is controllable to meet requirements and has heat recovery capability. Infiltration is essentially uncontrollable since it is mainly due to wind pressure, which is highly variable. Additionally, heat recovery is possible from air changes by mechanical ventilation but not from those which occur through infiltration

The amount of infiltration that occurs through various openings on surfaces is readily calculated when materials and frequency of use of openings such as doors is known. In the case of windows, the rate of infiltration is directly proportional to the lineal dimension of

3.3 Infiltration

crack that is openable. Other methods use a factor times the gross area of glass to arrive at this value Manufacturers of fenestration units and various code bodies publish these factors.

3.3.3 Air Leakage

Air leakage occurs at elevator and stair shafts, exterior doors, openable windows and to a lesser extent, through the skin of the building.

Elevators, stair shafts, floor construction, interior partitions and service shafts are major separations in a building Although they provide internal resistance to air flow, their air leakage characteristics must be identified in order to determine infiltration through outside walls and air flow pattern within a building In cold weather, most upward air flow is inside vertical shafts which provide the least resistance path from floor to floor and are therefore the main avenue for transfer of odours and air contaminants.

Exterior doors, depending on the orientation type and use, are a source of air leakage. For residences and small buildings where use is infrequent, leakage can be estimated on the basis of operable crack length between the door and frame For a well fitted door, leakage approximates a poorly fitted double hung window, for a poorly fitted door, the figure may be doubled A frequently opened single door, as in a small retail store, may have a value three or more times that of a well fitted door as an allowance for opening and closing losses

Swinging and revolving doors are generally essential on high rise buildings where entrance leakage is severe due to stack effect.

Another means of air leakage control is the air curtain In this method a jet of high velocity air is blown across an opening to separate indoor and outdoor conditions This can be 60% to 80% effective in low buildings but is not recommended in high-rise buildings or industrial buildings with high negative pressures due to high exhaust rates Air curtains tend to be inefficient in cold climates

Dramatic reductions in air leakage through brick masonry and frame walls can be achieved with use of a good interior finish Plaster is an excellent barrier against air leakage and will reduce the leakage through an unplastered block wall by 96% Water base paint reduces leakage by 50% and three coats of oil base paint 28% when applied to an unpainted plaster surface

3.3.4 Stack Effect

Air density varies with temperature In cold weather with lower density inside a building, air rises and is replaced by outside air infiltration at its base In summer the infiltration will occur at the top of a tall building and exfiltration at the bottom. A building 120 m high can have a pressure difference across the outside wall of 175 Pa resulting from a temperature difference of 56°C.

Stack effect could be eliminated in high buildings if it were possible to seal the building horizontally at each floor. This is impossible since stair and elevator shafts are required in high building

In extremely tall buildings, exceeding approximately 35 storeys, serious consideration should be given to providing a relatively air

tight horizontal separation at the midpoint of the building This can be done by using vestibule air locks in the stair shafts, at the mid-point or at the elevator transfer floor(s) Air movement can be controlled in elevator shafts by using air locks at transfer floors. In elevatoring systems where all elevators original at the base of the building, revolving doors can be used at the base entry vestibule of upper elevator zones

A tower located on a one or two storey podium presents special air movement problems due to the stack effect on the building The shopping podium by nature can have many non air lock openings If there is a direct air path to the base of the tower, such as exists with escalators, high air velocities can occur Some method of air lock must be introduced at the top of the escalator opening prior to the entry into the base of the tower area. Where possible all outside entrances to the podium should have vestibule air locks. Inward facing shops should have the main, high use, outside entrances equipped with revolving doors or vestibules

Exhaust of stack or unwanted contaminated air can occur at the low rise or podium level if the proper system of air locks is used. Reverse flow will occur in these systems at certain temperature conditions if the air movement to the tower base is not controlled Care must be taken to direct exhaust away from any openings where negative pressure is created by infiltrating air which would carry the exhausted air back into the building

See **Figure 3.3.4-1** Theoretical draft in buildings due to chimney effect, **Figure 3.3.4-2** Pressure characteristics of a building

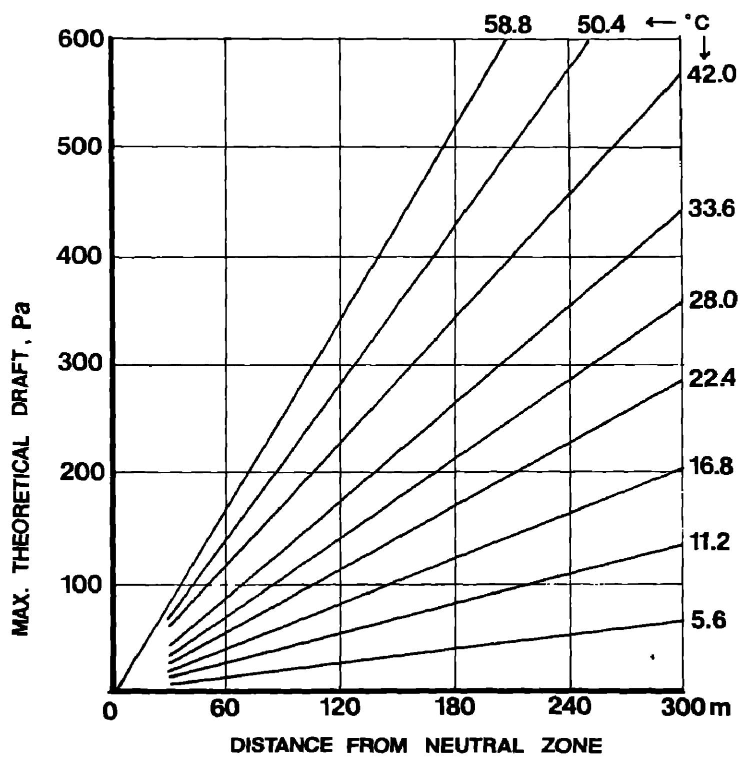
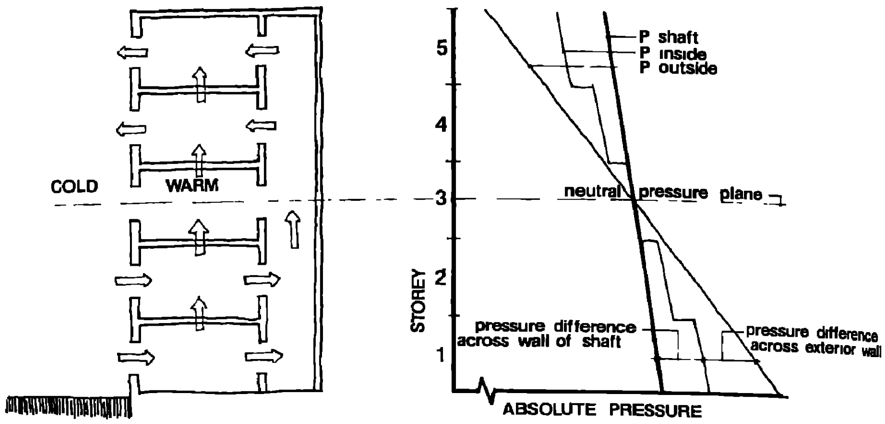
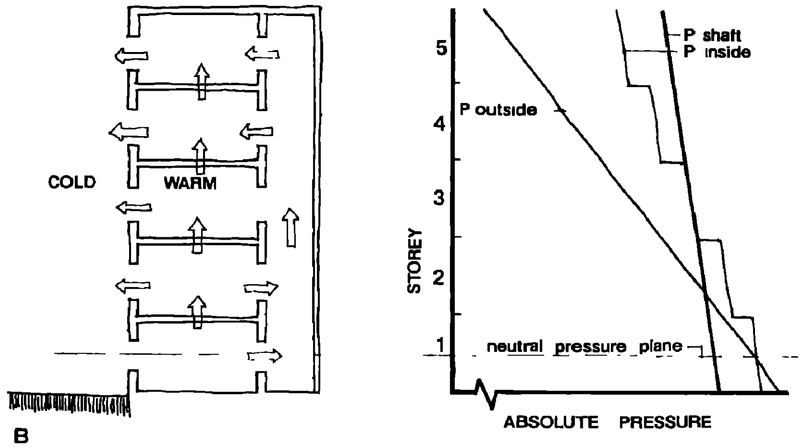


Figure 3 3.4-1
Theoretical draft in buildings due to chimney effect



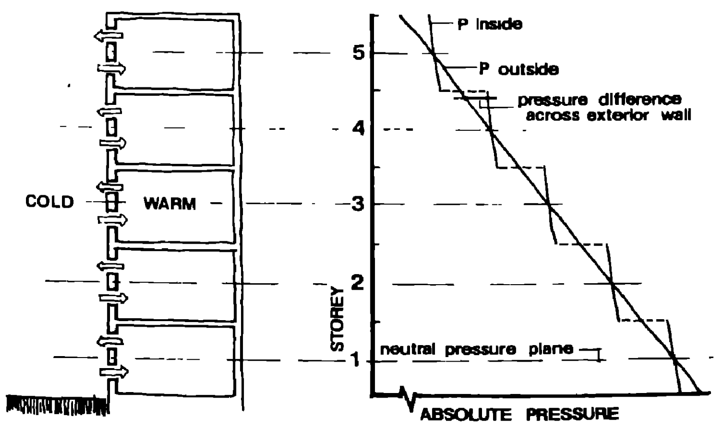
A.

Heated building, uniform distribution of openings through enclosure Floors and walls of elevator shaft



B

Heated, pressurized building



C.

Heated building, complete isolation of each storey with equal openings at top and bottom

Figure 3.3.4-2
Pressure characteristics of a building.

3.4 Electric Power Supply

3.4.1 Power Needs for Electric Resistance Heating

A well engineered electric resistance heating design will include many provisions for energy saving Refer also to Section 3.8.6 regarding the use of a high grade form of energy, electrical power, for a low grade energy function i e space heating

3.4.1.1 Energy Saving Design Considerations

Important factors to consider are capacity, voltage regulation, accessibility, flexibility and control These are equally pertinent whether the design is for a complete distribution system, or just a segment The ultimate electrical system, within economic limitations, will be efficient to operate, meet existing as well as future requirements, and lend itself to easy maintenance and alteration Financial incentives, a new energy ethic, and continued education are necessary to implement a major energy conservation program not only in electric resistance heating equipment, but also in control equipment and devices, such as centrally controlled and pre-program function control systems

.1 **Voltage Drop**: Voltage drop must be taken into consideration in the design of feeders, branch circuit wiring, and over current protection Such a loss is caused by the resistance (and reactance in a c circuits) of the conductor to current flow Unless provision for this is made in calculating feeder and branch circuit conductor sizes, there may be a substantial difference between the voltage at the service and point of use It is necessary to compensate for such voltage drop, by increasing the size of conductor or reducing the length of circuit run

The Electrical Code states that a feeder conductor should be of such size that the voltage drop to the final distribution point (branch circuit load center or panel) of the computed load will be not more than 3% for power or heating loads, and not more than 1% for lighting loads or combined lighting, heating and power loads

Good practice dictates that a maximum voltage drop of 2% be assigned to feeders for power and heating loads A maximum of 1% drop should be maintained for lighting, heating and power load

The supply voltage is subject to change by the local power supply authority but not the drop within the building although it will be altered by the supply voltage

Allowable current-carrying capacities of insulated conductors in the Code are established on the basis of conductor insulation and room temperature These are the basic safety considerations that govern conductor size selection, but other conditions such as voltage drop, power factor, spare capacity, etc , must be included in the calculations

.2 **Oversized Equipment**: Detailed study and/or computer analysis should be used for load calculations and for determination of the energy load profile of the building.

If equipment is oversized due to excessive load calculations, it is costly, and inefficient, especially at part-load conditions.

Computer analysis should be used to calculate relative energy conservation benefits of alternative systems and construction materials Excessive safety factors should not be used.

The effect of lights, people, and storage should be recognized.[1]

.3 **Electric Power Demand Load Control**: Electric demand limiters with load-shedding devices, high-voltage interior electrical distribution systems, and power factor correcting condensers can all help energy conservation by controlling the maximum demand kilowatts Their effectiveness must be established through an engineering analysis for each project, and the building and its systems designed to accommodate them [2]

Loads controlled by a load stabilizer can usually be connected and disconnected at random without inconvenience to the building function

Electric space heating systems of all kinds are ideally suited to such control

3.4.1.2 Type of Equipment and Application[3]

There are a great many types of electric resistance heating equipment on the market today

The following guide lines will assist in determining which best combine suitability for a particular location with energy efficiency

Most electric resistance heaters are available for standard voltages, single or three phase It is vital that the heater nameplate voltage match the supply voltage It is recommended that reference be made to the Electrical Code and/or the local inspection office for applications utilizing 250 volts or over

All electric resistance heating equipment is equipped with built-in safety devices for over-temperature protection These cut-outs need no resetting—they are completely automatic

The energy-saving advantage of using indivually controlled units in larger buildings, such as hotels, institutions, schools, etc. is that they may be switched off when specific room areas are not occupied This will result in less energy consumption than a main furnace supply system

A summary of available types of electric resistance heating units and a brief description of their operation follows

.1 **Residential Baseboard Convectors** Residential baseboard convectors give perimeter heating, spreading a balanced convection-radiant warmth over floors and outer walls They are largely used in residential design, but have application in the commercial and industrial markets

.2 **Commercial Baseboard Convectors**: These are mounted approximately four inches from the floor and thus provide the necessary clearance for floor maintenance Generally found in school corridors, washrooms, hotel corridors, motel corridors, or in any location where the unit can be subjected to abuse from cleaning equipment or the general public

.3 **Convection Cabinet Heaters**. Convection cabinet heaters are designed to permit easy access through the bottom louvres The air is then heated by means of the metal sheath heater, and convected upward and outward through the upper louvres These electric heaters are particularly suited for mounting in entrance-ways, lobbies, corridors, offices, reception rooms, and school classrooms

.4 **Forced Air Console Units**: Forced air console units (due to their high recovery rate) are designed primarily for application where large quantities of heat are required. Application areas are large

entrance-ways, lobbies, corridors, reception rooms, department stores, large offices, restaurants, bowling alleys, stores, passenger terminals, and the like.

.5 **Wall Insert Fan-Forced Heaters:** Wall insert fan-forced heaters are suitable for entrance-ways in smaller commercial buildings, washrooms, kitchen areas, etc These fan-forced units are flush-mounted and have the added feature of fast recovery for areas where there is a great amount of infiltration such as in vestibules

.6 **Vertical Blower Unit Heaters:** These offer a practical and economical solution to space heating problems encountered in industrial and commercial buildings Typical locations for this heater include factories and entrance-ways in stores or office buildings

The unit is designed to discharge a large volume of heated air at relatively high velocity and low temperature down to work levels The vertical unit blower comes in various sizes and voltages All unit blowers are equipped with thermal cut-outs which safeguard against an accidental stoppage of air flow.

.7 **Duct Heaters:** Duct heaters allow easy application of electric heat to both new and old duct systems used in distributing conditioned air to either living or working spaces They are suitable for any duct system such as gymnasiums, general purpose rooms, or as terminal reheat in central systems

One of the main features of the ducted system is in branch ducts for room-by-room or area-by-area temperature control The zone control for precise comfort heating can be obtained easily by electric duct heaters

.8 **Floor Drop-in Units:** Floor drop-in units are not commonly used in commercial buildings but may be found frequently in apartment buildings and motels in front of balcony doors or low windows

.9 **Blower Type Unit Heaters:** These have a definite application in the commercial and industrial field The fan-forced unit comes in a great variety of sizes to suit each individual application

Some more popular applications are in sub-stations, greenhouses, power plants, stores, warehouses, showrooms, public buildings, lobbies, store entrances, factories, garages, guardhouses, and ticket offices. As this unit is fan driven, consideration should be given to noise where this could be a factor

.10 **Unit Ventilators:** Unit ventilators are commonly used in school classrooms Other applications are conference rooms, auditoriums, or areas where individual ventilation is required

The unit ventilator has many features, including built-in modulating controls, built-in automatic night set-back control system complete with seven-day clock and night-setting thermostat, and built-in override timer to interrupt 'no occupancy' system for temporary full heat in evenings or weekends Each room becomes a self-contained entity.

Installation is simplified as most units are available complete with heating, ventilation and controls, and require a very simple connection to the power supply

.11 **Warm Air Systems:** Central blower and air duct systems are adaptable when summer cooling is planned or when circulation, filtering, humidifying, or dehumidifying of the air is desired.

Such systems furnish a convenient means for positive intake of fresh air, and of reheat for summer control of humidity Individual room control may be obtained by using electric duct or air outlet heaters Electric furnaces consist of resistance heating coils and a blower housed in an insulated cabinet

.12 **Infrared Heating and Equipment**. Where buildings or areas contain a considerable volume of air to be heated, or where the heat losses are excessive and continuous e g sport arenas, infrared reflectors project energy to the persons or objects to be heated Infrared energy being radiant does no heating until it is absorbed by an object For this reason, the heating system is economical and energy efficient. Sectional focusing, through-type reflectors, are made with low temperature resistors, or with metal sheath, quartz tube or quartz lamp elements, and are suspended from the ceiling or bracketed from the wall

Rated capacities from 650 to 5 000 watts per linear metre of unit are available. In buildings with exceptionally high ventilation load where convection heating is economically impractical, infrared heaters are employed to provide relative comfort despite low ambient temperatures

Installations may be for complete area heating or just the heating of specific areas occupied by personnel There is growing use of infrared spot heating in out-door locations with energy conservation programs, but these must have a wind break to be effective

Two examples of applications for infrared are
—buildings with high ceilings
—buildings which cannot be insulated properly

.13 **Floor Heating Cable**. Resistor cables of the same type used for ceilings may be used for panel systems in concrete slabs except that the insulation of the cable must be capable of rougher handling and must be impervious to the chemical action of the concrete in which it is imbedded Special or heavy duty cable for concrete installations is available

Some floor heating installations employ reinforcing grids or a separate wire mesh energized at low voltage The system is specially suited for space heating not requiring large temperature differential in adjacent areas The use of wire mesh or special cables has a particular advantage in ground floor areas In such locations the thermal capacity of heavy concrete floors forms an energy reservoir which can be exploited in utilizing electrical energy at reduced 'off-peak' rates or end rates in the energy conservation program The floor temperature should not exceed 22°C for occupant comfort A discussion of the mass thermal storage effect in buildings is to be found in **Section 3.2.3**

.14 **Ceiling Heating Cable**: This type of system usually consists of electric resistance cables imbedded in gypsum plaster whereby the whole ceiling of a room becomes a radiant heating panel

The use of vermiculite or other insulating plaster is not suitable as it causes the cable to overheat and also reduces the radiant effect of the ceiling.

A highly sensitive room thermostat with narrow operating differential is recommended for each room.

In some areas, imbedded heating cable is prohibited for installation in wall sections because of possible danger from mechanical damage. Regulations of local authorities should be checked first.

.15 **Prefabricated Ceiling Panels with Heating Elements:** A variety of prefabricated ceiling panels is available for either full room or supplemental electric heating. Panels are made of gypsum board, rubber, glass, steel, or other materials The heating elements are imbedded conductors, laminated conductive coatings, or printed circuits Electrical connectors or non-heating leads are provided as part of each panel Panels may be either flush or surface mounted and finished as part of the ceiling.

3.4.1.3 Heat Pumps

The reader is referred to **Section 3.13.1** in which the operation and potential of heat pumps is discussed in detail

3.4.2 Power Needs for Water Heating, Cooling, Refrigeration

3.4.2.1 Power Needs and Conservation[4]

This section deals with conservation of energy used for service hot water in existing or new buildings

.1 **Insulation of Hot Water Storage Tanks and Piping:** All hot water storage tanks should be insulated so that the heat loss is no greater than 47 W/m² of external tank surface area The design ambient temperature should be no higher than 18°C

All hot water re-circulation piping systems should be limited to a maximum heat loss of 79 W/m² of external pipe surface above ground The maximum heat loss from external pipe surface below ground should not exceed 110 W/m² These heat loss calculations are determined by using a temperature difference equal to the maximum water temperature minus a design ambient temperature no higher than 18°C

Non-recirculating systems should have the first 2 5 m of piping insulated as if it were part of the storage system

.2 **Water Temperature:** The recommended maximum supply temperature of service water is 41°C Where kitchen equipment, laundry facilities, or other special applications require higher temperature water, booster heaters or separate piping systems should be employed

3.4.2.2 Design Considerations

.1 **Circulating Pumps:** Circulating hot water systems should be arranged so that the circulating pump(s) can be conveniently turned off (either automatically or manually) when the hot water system is not in operation.

.2 **Location of Service Water Heating Equipment:** The service water heating equipment should be located as close as possible to the end use. For large areas, it is more economical and also a good energy saving system to provide several smaller water storage tanks near the end use.

Savings arise from the reduction in the length of the supply and return pipe system and in the elimination of a circulating pump.

It is more economical to run an electric branch circuit to smaller electric water heaters, than using a large water storage tank, circulating pump, supply and return pipe system The energy is saved by transferring energy with electrical wiring and cables, rather than water pipes

.3 **Shut-Down Disconnect Switch**: A separate switch should be provided for each hot water storage tank to permit de-energizing of the electric service of the water heater

The separate hot water tank electric feeders could be connected to a demand limiting system

.4 **Service Voltage**: Computations should be made to determine the service voltage that will produce the least energy loss That voltage use should be considered where practical

.5 **Electrical Energy Control**: Certain types of peak-shaving (demand limiting) controls are an aid to electric utilities and reduce energy demand charges for the user, (e g duty cycling, time-of-day limiting, demand limiting, instantaneous control) Local power companies should be consulted before deferring loads to off peak periods.

.6 **Flat Rate Electric Service**: Flat rate power service may be possible and local power companies should be consulted for the service arrangement and information about off peak periods

3.4.2.3 Air Conditioning and Cooling: Electrical Power Needs and Services

The electrical loads associated with air-conditioning equipment constitute a large portion of the total load of the building, usually 40% or more in a fully air-conditioned building The engineer designing the electrical system should consult with the engineer responsible for the air-conditioning system to determine this part of the load

In addition to the maximum kilovoltampere requirements, it will be necessary to know the approximate wattage of the largest motor anticipated, and the electrical engineer should propose the best method of starting the motors considering related mechanical and electrical problems

3.4.2.4 Auxiliary Equipment Power Service

The electric load for boiler room and mechanical auxiliary equipment will not normally constitute a large portion of the building load Usually, it will not exceed 5% of the total load (not including air-conditioning)

In small commercial buildings, the auxiliary equipment load will consist of small units, most of which will be served by low wattage motors. They may be one to two kilowatts or more in special cases While larger buildings have some low wattage equipment, the fans and pumps required may be quite large, 7 kW to 14 kW being common and 20 kW to 55 kW or more being quite possible

The electrical engineer should consult the mechanical designers on the possible use of large motors or electric heating loads which might effect the preliminary load estimate.

The major items frequently encountered are listed below
—induced-draft or forced-draft fans
—ventilation or exhaust fans
—pumps for boiler of condensate return, sumps, sewage ejectors, water circulation, etc.
—fire pumps and house-service tank pumps
—air compressors and service equipment
—electric heating and auxiliary heating elements
—control devices and circuits

3.4.2.5 Refrigeration Power Service (Apart from Air Conditioning)

This includes equipment for refrigeration of cooling rooms, walk-in type refrigerators, deep-freeze lockers, etc which have no connection with comfort cooling or air conditioning

The refrigeration and its electric load may vary greatly, depending on sizes of room or locker, final temperature, characteristic of product being cooled, etc.

The electric load in the average hotel, hospital and similar commercial buildings for this type of function is small and can usually be neglected in preliminary estimates.

Unusually large cooling spaces or freezers should be investigated.

3.4.3 Energy Storage Systems

Once an exceptional amenity, in recent years air conditioning has become an integral part of the mechanical system for many buildings

Many approaches have been taken and techniques utilized to reduce the cost of equipment, and increase efficiency.

A thermal storage system is basically an energy conservation tool. Used properly, it will save in ascending amounts

The first line of defence is to design buildings that reduce the impact of adverse weather conditions on HVAC systems.

3.4.3.1 Energy Storage for Energy Conservation and Management

Heating and air conditioning starts with the building design Reference is made to the effect of building geometry and volume on energy consumption elsewhere in this Handbook (Ref Section 4.3) It is worth repeating that a round building has less exposed exterior surface, hence less heat gain or heat loss than any other shape for an equivalent floor area A square building has less surface than a rectangular one for equal square metre area but the rectangular building with the longer sides facing north and south suffers less solar heat gain in the summer.

Buildings partially below grade or employing berms reduce solar gains and thermal transmission losses

Electric demand limiters with load-shedding devices, high-voltage interior and exterior electrical distribution systems, and power factor correcting condensers can all contribute towards energy conservation. The effectiveness of these devices must be established through an engineering analysis for each project, and the building and its systems require appropriate design for their accommodation.

Over-sized heating and cooling equipment are wasteful energy users Systems should be designed on a modular basis, so that smaller pieces of equipment including boilers, oil and gas burners, cooling towers, pumps and fans are operating continuously at their peak capacity to provide the best ratio of power consumption to performance.

Sufficient temperature control zones should be provided so that there are not large areas which become over-heated or over-cooled due to their load variations compared to the control zones

Inside buildings, the HVAC system must be designed to counter internal heat gain from lights, equipment, and people in spaces that are cooled In summer this is a matter of finding the most efficient means for rejecting the heat (Thermal Storage Reservoir ref Section 3.4.3.2) But in winter, operating costs are reduced by capturing as much heat from the inner space as can be done economically and redistributing it to the colder perimeter space

Having optimized the shell and the interior, the resources of 'free' energy from the sun, outdoor air, and water in lakes, streams, and wells, must be explored and cost-effective means for utilizing them found

Load-management devices and systems can be used to avoid unwanted peaks of demand upon energy-supply systems

Examples are control systems that cycle equipment during peak periods or storage systems that build up a reserve of heating or cooling during off-peak periods These techniques can save the building owner operating costs if, as a result, demand charges are reduced or completely eliminated There will also be less consumption of energy if they permit energy suppliers to cut back on, or cease operation of less-efficient equipment used to meet peak loads

3.4.3.2 Thermal Energy Storage

Thermal energy storage is the most promising technology for both residential and commercial storage in the near-term for space heating/cooling and hot water

Heat pumps with auxiliary storage systems offer great potential, solar energy with thermal storage in liquids or solids, and phase-charge materials as a storage medium are here or on the way Batteries may be used in the future.

The major barrier to immediate application of residential thermal storage is economics Utility rates require modification before consumers are likely to be induced to install storage systems High first cost is a major barrier, particularly to single-family home purchasers

Storage in homes could be controlled (radio or ripple control) by utilities

Significant retrofit is expected only when a primary heating/cooling unit is replaced, otherwise it is not cost effective

Resistance to new technologies, particularly on the part of small home builders, must be overcome.

Financing of thermal energy power storage systems in new homes may be a problem since there is a lack of aggressive interest in the financial community.

3.4.3.3 Thermal Energy Storage: Advantages

The basic purpose of thermal energy power storage is to reduce the cost of the following
—heating—by saving fuel
—cooling—by saving electric demand
—extending existing chilled water plants

3.4.3.4 Thermal Energy Power Storage for Saving Heat

Commercial buildings are thermal generators Even in a Canadian winter, buildings gain as much heat from the sun and internal sources as they lose through their envelope and ventilation systems (Ref **Section 3.1.5**) Savings in energy required for heat could be achieved by
—defining heat losses and gains for a well designed building
—balancing heat losses and gains
—converting heat gains to useful heat
—heat reclamation vs storage capacity and balanced temperature

3.4.3.5 Thermal Energy Storage for Saving in Cooling

Electric drive is more efficient for cooling despite low thermal performance at the generating plant.

For reasons of fuel conservation, the use of steam driven refrigeration will diminish in the future especially when owners are made aware that *storage can help to offset the main cost of electric* cooling—namely, the demand charge

3.4.3.6 Chiller Demand vs Storage Capacity

The design and scale of storage should be examined and compared with the electric demand-shaving potential at the chiller For example, the energy consumption of a 3500 kW chiller can be reduced 20% simply by storing just 10% of the load

The effect of demand for refrigeration on electric cost can be an important consideration It is usually imposed on top of the electric demands for lights, fans and pumps Hence, the savings for operating some or all of refrigeration off demand can be significant.

Municipal electric rates will vary with location but almost all will show important savings for reducing the peak requirement. Let us take as an example a 1000 kW water chiller operating for 250 equivalent full load (EFL), hours per month in Toronto The charge at 1979 rates for demand and energy will be $9,180. If a 385 kW water chiller is substituted to provide the same effect in conjunction with storage, by operating 650 EFL hours per month, the cost will be proportionately less.

3.4.3.7 Cost of Electric Energy

Electricity is usually billed monthly as some blend of peak demand and energy. The 1979 cost of demand power in Toronto was $2.50/kW per month. The demand kilowatts cost, or charge, pays amortization. The rate for energy kilowatt hours was $.025/kW·h and this pays fuel and wages. From the foregoing, the high cost of demand power in comparison with energy kW·h cost is quite evident.

In terms of energy conservation, the main objective for all designs should be low demand kW. This can be achieved with thermal and/or electric energy storage

3.4.3.8
Water Off-Peak Thermal Storage

Throughout a 24-hour period, the demand for electric power in most service areas fluctuates widely Typically, it is lowest at night, then rises to a morning or early evening maximum Frequently, electric utilities are obliged to bring less-efficient standby units on line to meet these peak demands

It could be advantageous, not just for the utility, but for its customers if some electrical usage that normally would occur during a peak period could be transferred to off-peak hours This load could then be served by more efficient base-load generators The customer would benefit because utility rates are based upon the cost of production and delivery

In buildings, heating, and even cooling, loads can be transferred through thermal storage With respect to heating, thermal storage systems can save heat captured from internal sources and also will store generated heat over night. With cooling, there is no energy saving, per se, but demand load can be shifted and the owner can save money through lower charges in this regard Refer also to Section 3.4.3.3 above

Additionally, by running the chillers at night and storing the chilled water, the size of chillers can be reduced

One conceptually simple, yet sophisticated, proprietary system, called 'Megatherm,' employs a sealed, heavily-insulated water tank with immersion electric-heating elements During off-peak hours, a time control energizes the heating elements to raise water temperatures to 150°C or more This high temperature is possible because a pressurized vessel is used During the day, the heaters are off, and the stored heat is transferred by circulating water through heat exchangers sealed within the tank Figure 3.4.3.8-1.

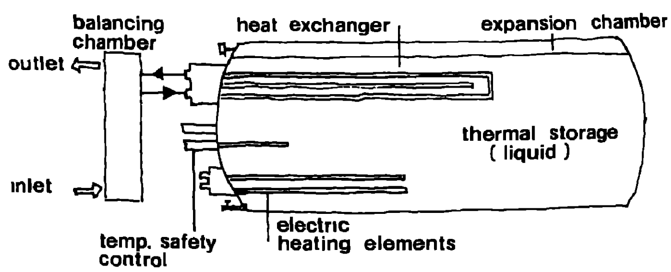


Figure 3 4 3 8-1
Off-peak thermal storage, water type [5]

3.4.3.9
Solid Core Off-Peak Thermal Storage

Another type of thermal storage system of much smaller scale, appropriate for housing and small office buildings, incorporates a solid core of high-density mineral or refractory bricks in small-size units. It can be installed directly in a basement or heater room.

The core can be 'charged' with the heat equivalent of 200 kW·h during off-peak hours. A portion of the return air in this ducted-air system is shunted through the core when heat is required. A con-

trol damper regulates the amount of return air that passes over the bricks, and thus the amount of heat delivered Systems such as these have been used in Europe for a number of years and are now being manufactured in the United States They have been installed under some form of priority control for electrical usage

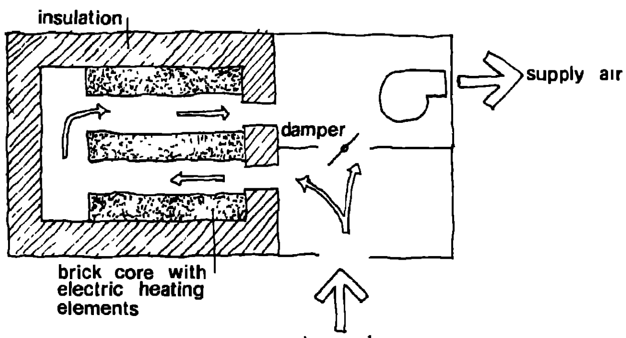


Figure 3 4 3 9-1
Off-peak thermal storage, air type [6]

3.4.4 Electrical Distribution Systems

3.4.4.1 Design to Minimize Consumption

The electrical distribution system should be designed to minimize the consumption of electrical energy. The intent of this section is to set forth requirements and considerations that apply to new and existing design, as well as additions and/or alterations to electrical distribution systems

3.4.4.2 Design Considerations

.1 **Increased Power Factor**: Equipment with marked utilization ratings greater than 1000 W and lighting with ratings greater than 15 W with an inductive reactance load component, should have a power factor of not less than 85% under marked rated load conditions.

Equipment with a power factor of less than 85% should be corrected to at least 90% under rated load conditions.

Power factor corrective devices installed to comply with this criterion should be switched with the utilization equipment, except where this results in an unsafe condition or interferes with the intended operation of the equipment

.2 **Service Voltage**: Where a choice of service voltages is available, computation should be made to determine which service voltage would produce the least energy loss. That voltage should be selected.

.3 **Voltage Drop**: In any building, the maximum total voltage drop should not exceed 3% in branch circuits or feeders, for a total of 5% to the farthest outlet based on steady state design load conditions.

3.4 Electric Power Supply

.4 Lighting Switching: Switching should be provided for each lighting circuit, or for portions of each circuit, so that task lighting and that required for custodial purposes or to supplement natural daylight may be operated selectively

.5 Oversize Motors· All motors rated at 3 kW and over should be checked for load factor (LF) and consideration given to replacing any motor with a load factor less than 0 5 Consideration should be given to replacing a motor if.

(a) the energy conversion efficiency is less than 88% of a motor's maximum efficiency, and

(b) at least 7% increase in efficiency will be obtained using the replacement motor

.6 Electric Motor Efficiency: An electric motor is considered inefficient whenever the rated load energy conversion efficiency from electrical to mechanical energy is less than the minimum percentages shown in **Table 3.4.4.2-1**.

Whenever motor replacement is being considered, the replacement motor must have a minimum efficiency greater than the above values

Motor Nameplate	.Minimum Efficiency at Nominal Speed and Rated Load
0 746 kW (1HP) and above to	79%
1 1 kW (1½ HP)	81%
1 5 kW (2 HP)	82%
2 2 kW (3 HP)	83%
3 7 kW (5 HP)	84%
5 6 kW (7½ HP)	86%
7 5 kW (10 HP)	87%
11 2 kW (15 HP)	88%
14 9 kW (20 HP)	88%
18 7 kW (25 HP)	89%
37 3 kW (50 HP) and greater	90%

Table 3 4 4 2-T$_1$
Electric Motor Efficiency

.7 On-Site Power Generation: When extensive replacement of combustion equipment and boilers is contemplated or when existing conditions make it feasible, on-site power generation should be considered.

.8 Off-Duty Scheduling of Electrical Loads: All electrical loads should be provided with accessible automatic or manual devices to shut down equipment or turn off the lights in areas not being utilized.

.9 Electrical Energy Control: Demand limiting (peak shaving) should be considered Certain types of demand limiting controls are an aid to electric utilities and reduce energy demand charges for the user, (e.g. duty cycling, time-of-day limiting, demand limiting, instantaneous control). Local power companies should be consulted when loads may be deferred to off-peak periods.

.10 Main Electrical Supply Service: The electric supply service connection to the building should be located as near as possible to the building's main electrical and mechanical loads.

.11 **Electrical Service for Elevators:** The elevator electrical system should be checked to confirm that when there is no call for the elevators, they are in the park and rest position In this way, only the control circuit is energized without the connected load and the cab lights

3.4.5 Transformer Efficiency

3.4.5.1 Power and Distribution Transformers

All large buildings, commercial, industrial and large scale residential developments, have power and/or distribution transformers

3.4.5.2 Design Considerations

.1 **Transformer Location:** Relocation of existing transformers should be investigated to ensure that they are located as close as possible to the loads they serve

.2 **Transformer Taps:** Transformer taps should be set as high as possible, consistent with the voltage rating of equipment served and safety considerations.

.3 **Transformer Losses:** In order to eliminate 'no load' transformer losses, transformers should be de-energized when unloaded for long periods, e g transformers for athletic fields during non-use periods, air conditioning, chiller or heating equipment transformers during off-season, and transformers supplying other unoccupied or unused spaces or equipment. If disconnect means are needed, they should be installed

3.4.5.3 Maintenance

A semi-annual inspection maintenance program should be established in order to ensure that·

—all connectors are tight
—switchgear is free of dust
—transformer is not overheating

Corrections should be made as required

3.5 Building Physics

3.5.1 Physics of the Building Envelope

The envelope, or skin, of a building is the interface of the desired internal environment and the expected external environment. The objective is to control the interaction between the two environments sufficiently to maintain interior comfort conditions Energy conservation requires this to be done with a minimum total expenditure of energy on the fabric of the envelope and the operation of any interior systems

The energy cost of the fabric is the sum of the energy represented by the manufacture, processing, erection and maintenance of the totality of its components in place, less the net salvage energy reclaimable at the expiration of its useful life The operational energy represents the energy expenditure necessary to maintain comfort conditions, including lighting, and to permit the building to function

3.5.1.1 Energy Content

Information on the energy content of buildings has only recently received attention There is an excellent discussion by Richard Stein in 'Architecture and Energy' [1] Metric values derived from data in that book follow. Table 3 5.1.1-T_1.

Item	Energy Content	
Materials		
rough framing lumber	$35{,}120 \times 10^5$	J/m^3
double strength sheet glass	$1{,}753 \times 10^5$	J/m^2
ready mix concrete	$35{,}835 \times 10^5$	J/m^3
oil and alkyd paint	$1{,}363 \times 10^5$	J/L
asphalt roofing shingles	$2{,}880 \times 10^5$	J/m^2
hot rolled structural steel	435×10^5	J/kg
insulation (unspecified) 110 mm	780×10^5	J/m^2
common brick—one	151×10^5	
Fire resistant floor construction, high rise building		
steel with concrete fire proofing	33,326	J/m^2
reinforced concrete slab	28,555	J/m^2
composition construction	19,553	J/m^2
Wood frame exterior walls, $U = 0\ 4\ W/m^2/h/°C$		
stud wall, wood shingles, insulation int finish	3,670	J/m^2
stud wall, brick veneer, insulation int finish	19,441	J/m^2

Table 3 5 1 1-T_1
Energy content of building materials and construction

When comparing these values the designer should also evaluate expected life, maintenance, potential recycling of the building for changed use, demolition and salvage If the designer selects energy economic materials and uses them economically there can be substantial energy savings as construction energy represents about 10% of the national energy budget

A typical high rise, pre energy crisis, office building consumed about four times its annual operating energy consumption during construction. With energy conserving design and operation, consumption could be cut by a factor of four, thus changing the ratio to 16 to 1 Obviously, we must try to reduce the energy cost of construction and at the same time spread it over a longer building life.

In the case of structural systems, rational rather than arbitrary selection of live loads can yield further economies, though potential future use and potential recycling may limit this. Constant section structural members represent an excessive use of material in all areas

but that of maximum stress However, the saving is less than indicated by a number of authorities who based their comparisons on the minor case of simple spans Turn of the century highway bridges and present day construction crane booms are excellent examples of optimum utilization of material Unfortunately, economic use of materials generally carries energy penalties for design time and for manufacture in plant or on site

3.5.1.2 Mass

The mass of a building provides a flywheel effect through its thermal storage capacity as discussed in **Section 3 1.5**, Thermal Capacity Heat Storage and Pre-cooling If this mass is exterior to the insulation layer, it will not appreciably affect energy use, but may even out demand and may slightly reduce cooling system size Where maximum temperature variation is daily rather than seasonal massive buildings may provide acceptable internal environments with little or no energy inputs Unfortunately, while this may apply in Mediterranean type climates it is not so applicable in the Canadian climate where seasonal changes will require energy inputs, independent of mass, in the majority of cases If the mass is internal to the insulated envelope, it may then be used to store excess thermal energy from solar or internal heat gains for later release when these loads are down Refer also to **Section 3.6.4** for a comparison of the relative merits of internal and external locations for insulation.

Effective use of the passive thermal storage requires acceptance of a temperature differential during working hours. Active thermal storage systems may make use of the thermal capacity of portions of the building, adjacent earth, and insulated thermal storage or a combination of these to operate within normally accepted temperature differentials Careful analysis is required to fully exploit the potential of mass

3.5.1.3 Surface to Volume Ratio

Minimum exposed surface per unit floor areas will give minimum losses and gains through the building envelope The implications of this in terms of appropriate architectural form for energy conserving buildings are examined in **Section 4.3**, Building Form

3.5.1.4 Heat Flow

Heat is absorbed, reflected, transmitted and emitted by the envelope of a building in a number of ways which marginally come under the definition of physics These are discussed in this Handbook under the headings Thermal Conductivity **Section 3.6.2**, Natural Ventilation **Section 3.9.3**, Stack Effect **Section 3.3 4**, Convection and Radiation An examination of Convection and Radiation follows

3.5.1.5 Convection

Convection is the transfer of heat by movement of fluid.
.1 The Thermal Head Convection: In the building envelope we are concerned with convection air currents powered by the expansion of warmed air and the contraction of cooled air In an air space in walls, the movement will be up the warm surface and down the

cold surface This can effectively short circuit insulation; that is, cancel its value, when there are sufficient air spaces to allow circulation around it. The effect is the same in horizontal air spaces when the warm surface is on the bottom, as in a roof There is no effect when the cold surface is on the bottom, thus explaining the higher *RSI* values given in the tables for heat flow down in a given air space The effect is minimal in narrow air spaces due to surface friction

Where air spaces connect to the exterior and are outside the insulation and vapour barrier they may properly function to equalize air pressure across the exterior skin and to carry off any moisture accumulation, such as may build up during the summer cooling cycle through condensation This moisture may also be driven into the space by kinetic energy during a heavy wind and rain storm The openings connecting such a space to the exterior should not be excessively large or the convection currents will be strong enough to degrade the value of porous unprotected insulation and strong enough to introduce excessive moisture from rain, or from condensation during the cooling season

Preferably, the insulation should be protected with a water resistant surface of high permeance This is not always the case in envelope components marketed as a complete package Equally, such spaces should be limited to less than floor height to limit the thermal head, and should be limited in width so that the same space cannot be subject to different exterior pressures

.2 **Kinetic Convection—Air**: In this case the transfer of heat by a fluid moving through the building envelope Any air movement into a building will be exactly balanced by air movement out, and that air will carry energy, either from heating or cooling There is probably more energy lost through excessive air movement than from inadequate insulation The energy for this movement can come from wind, creating pressure on one side of a building and suction on the other, from the ventilation system maintaining positive or negative pressure and from thermal head or 'stack effect' within the building.

.3 **Ventilation by Kinetic and Thermal Head Convection**: Natural ventilation can be provided by both kinetic convection and thermal head convection Kinetic convection is provided where there is a pressure differential across a building, openings in both low and high pressure areas, and no barrier blocking the flow within the building between these two areas

The rule for thermal head ventilation is simply to allow air to enter at a low level and exit at a higher level The greater the difference in elevation, the greater the natural flow developed. Where through floor ventilation is possible, its effectiveness may be improved by opening top units on the sun heated side and lower units of the shaded side Refer to **Section 3.9.3** for a review of the possible applications of natural ventilation in buildings Single openings at one level are relatively ineffective Factory windows of the last century were often triple hung with transoms over to provide the maximum potential natural ventilation

The stack effect in tall buildings without good air seals between floors will provide this same circulation on a building scale (Ref. **Section 3.3.4**).

3.5.1.6 Thermal Radiation

Radiation is the combined process of emission, transmission and absorption of radiant energy This transmission of energy through space from one body to another takes place without raising the energy level of the intervening space and this flow only takes place from a high level of energy to a lower level of the same form of energy

Radiant energy is our prime source of solar energy and in the recent abundance of reprocessed solar energy (fossil fuels and hydroelectric) we have tended to forget how readily it can be used to heat and light our buildings when we entrap and control it Unfortunately, it can also adversely affect some materials and can raise surface temperatures to levels that materially add to cooling loads Such temperatures can also increase differential movements to potentially damaging levels Maximum surface temperatures in Canada for dark surfaces can reach levels in the order of 110°C for horizontal roofs and 90°C for south facing vertical walls, particularly where there is reflection from other vertical and horizontal surfaces It can be fascinating to see sunlight reflected from a new glass walled building on to the north wall of an older building for the first time It may be disastrous for the cooling loads of the latter

All solid materials have a degree of rejection of radiant thermal energy (Ref Section 3 6.1 Surfaces, Finishes and Colours) Values of reflection and absorption vary widely with angle of incidence, the most so on very smooth surfaces such as polished metal or glass with reflection of about 8% at 0° incidence which will increase gradually to about 50° incidence and then increase rapidly to close to 100% at 90°. With glass and other transparent media, we have a portion of the incident energy penetrating without absorption so that in such cases reflectance and absorption are not complementary These values also generally vary with wave length (the higher the temperature, the shorter the wave length).

We can take advantage of these properties to alter materially the solar load on the exposed forces of a structure by angling surfaces to accept or reject solar radiation, by choosing surfaces of varying reflective values, and by carefully selecting glazing for its performance characteristics at different wave lengths. (Ref Section 3.6.5 Glazing)

Heat is lost from a building in the same ways that it is gained. We can take particular advantage of this for free cooling when we have glazing with a night sky exposure This will transmit heat by direct radiation to the cooler night sky and this loss can be controlled in the same manner as with heat gains Thus, on a hot night with proper window exposure, drapes should not be closed.

The ability of a surface to radiate heat, its emissivity, is discussed in Section 3.6.1.

3.5.1.7 Natural Light

Natural Light has been largely ignored in recent construction as witness the lack of differentiation between the various elevations of most buildings We can probably reduce by half the approximately 24% of our electrical energy presently being used for artificial light through more discriminating design and use, and we can reduce it even further if we make proper use of natural light This subject is discussed in detail in Section 3.14 Lighting

The human eye adapts easily to contrasts of seventy to one or more when outdoors and similar adaptability has been verified in interior classrooms

Windows and skylights have produced well balanced interior illumination in past traditional designs and can again if the same care is given to penetration and diffusion

Available natural light varies considerably and in Canada we need design values similar to those available in Australia, giving illumination levels which will be available during working hours. Australian values vary from about 3800 lm/m² to 11 800 lm/m² for levels which will be exceeded for 90% of the period from 8 a m to 4 p m while Great Britain has used 5400 lm/m², ref CBD [2]

Glare need not be a factor if shade is provided from direct sunlight and from highly reflective exterior surfaces The quality and quantity of natural light penetrating an interior can be modified by protective and directive devices, **Section 4.9** Protective Elements Illumination from a completely overcast sky is relatively uniform and independent of sun position, with horizon brightness about one-third of that at the zenith Internal illumination is generally calculated as a percent of the illumination on an unshaded exterior horizontal plane An overcast sky giving unobstructed illumination out of doors of 5000 lx is the standard for measurement This daylight factor is the sum of the sky component, and the external and internal reflected components

3.5.1.8 Water Movement

Water is governed by the same physical laws as air—it just behaves differently because of its greater density and its readiness to change state from solid to liquid to gas in the temperature ranges to which Canadian buildings are subject When water can penetrate a building envelope it can cause damage through rot, corrosion, erosion, destruction of materials and assemblies by the expansion force of freezing, deterioration of finishes, blistering and delamination from vapour pressure of trapped moisture and discomfort from uncontrolled humidity levels Of greatest pertinence for readers of this handbook is the fact that singly or in combination any or all of the foregoing can cause degradation of insulation and reduction in the insulating properties of the building fabric In brief, a successful envelope must be designed to resist the penetration, passage or absorption of water in all its forms and to encourage its departure in the right direction when it has penetrated, which it will

3.5.1.9 Vapour Flow

Atmospheric pressure is the sum of the pressures of each of the gaseous components of the air Each gas attempts to occupy all of the space at a uniform pressure

Water vapour is a gas and obeys the same laws Where a different pressure exists on two sides of a barrier, gas will attempt to diffuse through the barrier until pressures are equalized.

There is a limit to the concentration of water vapour which can exist in an air vapour mixture at any given temperature. The percent of this maximum present in air at a given temperature is known as its relative humidity, or RH. When the saturation vapour pressures are plotted against temperature we have a saturation curve. Thus for a

specific internal relative humidity, there is a specific internal vapour pressure and the saturation temperature of that vapour pressure is the point at which condensation will occur This is commonly known as the 'dew point' if above 0°C and the frost point if below 0°C

All materials have a permeability rating based on weight of vapour transmitted through a unit area in unit time, expressed as nanograms per (pascal second square metre) From the reciprocals of the permeability of the components of a wall, floor or a roof it is possible to calculate a vapour pressure gradient for continuity of flow. If this gradient curve falls below the curve of saturation vapour pressures plotted for the given wall, condensation will not take place under the temperature and humidity conditions assumed in the calculations

In brief, condensation can be avoided if the continuous flow (Pc) curve is kept below the saturation vapour (Ps) curve for all anticipated conditions The Pc curve can be adjusted by changing vapour flow resistances and the Ps curve by adjusting the thermal gradient Since construction tolerances adversely affect both curves a safety margin is required and the most effective solutions involve installation of high vapour flow resistant material (a vapour barrier) as close to the interior surface as practical and high thermal flow resistant material (insulation) as close to the exterior as possible A replot of both curves will then indicate the safety margin achieved Exterior vapour barriers, such as unvented metal, masonry, or membranes should be avoided Summer cooling can reverse vapour pressures and cause condensation on the outside face of a vapour barrier, but in such circumstances we do not have to deal with the same extremes of temperature or with the risk of ice or frost (except in special cases such as refrigerated buildings).

3.5.1.10
ional Stability

Excessive movement in a structure can destroy the integrity of a building envelope by creating openings that penetrate air and moisture barriers and allow unwanted air circulation through and around insulation These movements can be kept within acceptable limits by sound structural design that takes into account all potential loadings, deflections, creep and shrinkage. Maximum values for deflection, creep and short and long term shrinkage need to be determined and the necessary movement allowances incorporated in the building envelope if unpleasant surprises are to be avoided.

The components of a building envelope will all expand and contract with changing temperatures, unfortunately at different rates Certain synthetics may shrink if exposed to ultra-violet radiation Most materials will expand and contract with change in moisture content Wet process materials such as mortar and concrete will have substantial shrinkage while curing which may exceed the potential thermal movement Stress applied in excess of the elastic limit of a material will produce permanent deformation. Loose materials such as loose insulation can pack due to minor vibration Chemical or bacterial action usually requiring moisture, can cause serious damage to susceptible materials Therefore, the ideal building envelope assembly should allow for inherent dimensional changes such as curing shrinkage and dimensional variation due to structural movement and temperature change. It will also control air and moisture penetration and movement, and protect susceptible materials from ultra violet radiation

3.5.1.11 Acoustics

Walls for low-rise buildings, designed for energy conservation, may exploit the benefits of mass for both thermal storage and acoustic insulation (resistance to sound transmission) providing there are no air gaps or 'speaking tubes'

Walls for high-rise buildings, designed for energy conservation, need to be light weight for structural and erection economics and, therefore, require careful analysis to avoid acoustical transparency It is well to remember that resistance to sound transmission has no direct relationship to sound absorption.

Porous materials depend for their acoustic absorption rating on the entrapment and conversion of sound energy within the material They do not function efficiently for the reduction of sound transmission when there is free air movement on both sides However, a non resonant, rigidly braced unperforated surface can reject a substantial portion of incident sound by reflection, and can aid in the entrapment of sound energy in porous material, e g hard plaster on porous block

Without going further into the physics of acoustics it is sufficient to say that sound transmission can be reduced by sufficient mass to absorb the required amount of energy, by the more difficult expedient of multiple, separated, non resonant barriers, by the introduction of material other than sheer mass which will convert the sound energy to heat and by strict avoidance of metallic or air, 'speaking tubes'

Mass is the simplest, providing there are no free air passages around it where the vibration of an outer skin is transmitted through the air to an inner skin Where separated membranes are employed care must be taken that physical connection between the membranes is limited to energy absorbing spring connectors and/or massive non resonant components such as heavy structural members Loose fills or fibrous materials of reasonable weight can absorb appreciable sound energy but may be subject to packing and may complicate thermal and moisture gradient characteristics Patent fabrics of lead and vinyl can be used as fixed or loose membranes Transmission between parallel and similar membranes such as sheets of a glass can be minimized by an absorptive edge treatment, by using different thicknesses and/or patterns, by ensuring the membranes are slightly angled to one another and that there is no solid connection at the edges

3.5.2 Materials and Their Properties

The infinite number of materials, traditional and modern, that can be considered in the design of the building envelope for energy conservation is beyond the scope of this article No single comprehensive list exists Definitive values for many materials are not readily available, if at all, and the designer must base his decisions on his experience and knowledge of performance in place.

We need a constantly updated list of available materials, listing in particular and where appropriate, along with the usual physical properties, thermal conductivity, vapour permeability; water permeability, cost, initial energy content, salvageable energy content; resistance to oxidation, decay and other deterioration due to age, coefficients of dimensional change for age; temperature, radiation, moisture content and stress; fire resistance; flame spread;

acoustic permeance, resistance to radiation; emissivity, reflectance, toxic combustion products, change in physical properties due to age, temperature, radiation, moisture and stress

3.5.3 Temperature and Vapour Pressure Gradients

All areas of the building envelope should be checked for temperature range and vapour pressures

In this section we will determine the temperature and vapour pressure gradients for a typical roof in order to indicate temperature stress, heat flow, vapour flow and the possibility of condensation The methods of calculating are the same for other components, however, this example does not contain heat bridges or reflective lined air spaces

Calculations assume steady state or steady flow which are not strictly accurate assumptions, as the effects of solar gains, radiant losses, thermal storage and rapid air fluctuations are difficult to predict. Temperature preformance tests indicate that the assumptions made in assigning values to these, and to surface effects, are conservative

Precise values are not available for many materials and where necessary for continuity Imperial values have been loosely translated to SI

Permeance values vary with the method of test and both thermal and vapour flow values may vary with operative temperature ranges.[3]

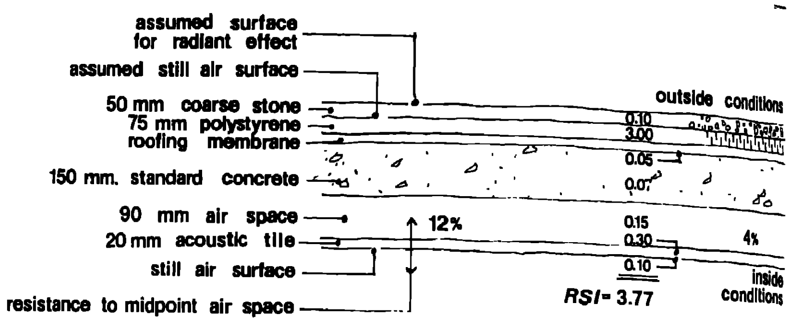
Having assumed a roof construction, a quick approximation of resistances will serve to assign performance temperature ranges It is helpful to determine radiant heating and cooling effects, surface coefficients, and air space coefficients in advance of the general calculations.

Most thermal coefficients are available in the 1977 edition of ASHRAE Fundamentals, chapter 22, although thermal resistance of plane air spaces requires conversion from imperial This Chapter also explains the use of the coefficients in determining a total thermal resistance In Canadian Building Digest No. 36 *Temperature Gradients Through Building Envelope,*[4] the construction by analytical and by graphical methods is described Chapter 20, ASHRAE Fundamentals entitled 'Moisture in Building Construction[5] explains the construction of vapour pressure gradients and contrasts the permeance values of many materials; these values will require conversion into SI

There are few examples of temperature and vapour pressure gradients for roofs and, since a major portion of energy passes through them, the following will explain the necessary considerations

3.5.3.1 Design Considerations

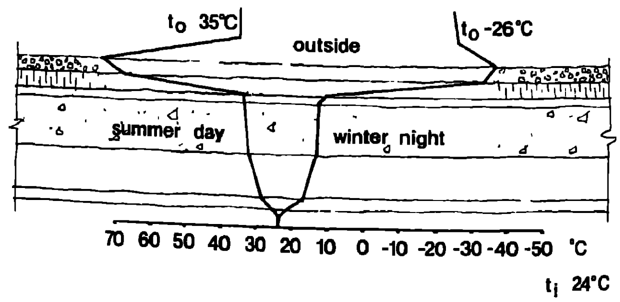
In Figure 3.5.3.1-1 a cross-section of a concrete roof construction is shown together with resistance values of the components It will be noted that the coarse stone does not have a resistance value but in this application it does create a still air film on the polystyrene and this film has resistance value as shown



RSI APPROXIMATION

Figure 3.5 3.1-1
Thermal resistance values, assumed roof construction

Before the temperature gradients can be established, the surface temperature of the outside surfacing material must be determined The temperature will be higher than air temperature in summer because of heat absorption from the sun, and lower than air temperature in winter because of heat radiation from the surface to the clear night sky The amount of solar absorption is based on the colour of the roof and its reflecting properties Furthermore, the mass density of the surface substrate will also be a factor as the higher density will react less quickly to temperature change The Canadian Building Digest No 70, *Thermal Considerations in Roof Design*,[6] gives recommended design values of the solar absorption coefficient for representative colours and weathered metals, as well as surface temperature changes due to substrate material In **Figure 3.5.3.1-2** the light grey surface with the low density insulation substrate increases in temperature in the summer to 71°C and decreases in the winter to − 36°C



THERMAL GRADIENTS

Figure 3 5 3 1-2
Thermal gradients, assumed roof construction

The construction of the vapour pressure gradients for continuous flow is similar to that for a thermal gradient, with the difference in potential being vapour pressure rather than heat energy, and the resistance of the material to vapour flow rather than heat flow The vapour pressure for the given relative humidities can be obtained from the Saturation Vapour Pressures **Table 3.5.3.1-T$_1$**.

SATURATION VAPOUR PRESSURES OF MOIST AIR					
Temp °C	Saturation Vapour Pressure, kPa	Temp °C	Saturation Vapour Pressure, kPa	Temp °C	Saturation Vapour Pressure, kPa
−30	0 038	−06	0 368	18	2 06
−29	0 042	05	0 401	19	2 20
−28	0 046	04	0 437	20	2 34
−27	0 051	−03	0 475	21	2 49
−26	0 057	−02	0 517	22	2 64
−25	0 063	−01	0 562	23	2 81
−24	0 070	0	0 610	24	2 98
−23	0 077	1	0 656	25	3 17
−22	0 085	2	0 705	26	3 36
−21	0 094	3	0 757	27	3 56
−20	0 103	4	0 812	28	3 78
−19	0 113	5	0 871	29	4 01
−18	0 125	6	0 934	30	4 24
−17	0 136	7	1 00	31	4 50
−16	0 150	8	1 07	32	4 73
−15	0 165	9	1 15	33	5 00
−14	0 180	10	1 23	34	5 34
−13	0 196	11	1 31	35	5 61
−12	0 215	12	1 40	36	5 91
−11	0 236	13	1 50	37	6 25
−10	0 259	14	1 60	38	6 52
−09	0 284	15	1 70	39	6 96
−08	0 310	16	1 82	40	7 37
−07	0 338	17	1 94		

Table 3 5 3 1-T_1
Saturation vapour pressures of moist air

To test for the possibility of condensation, it is necessary to construct a saturation pressure gradient, **Figure 3.5.3.1-3**. This is done by taking the known temperature at the interfaces between the roof components and plotting the corresponding saturation pressure for these temperatures. When the curve of continuous flow does not intersect the curve for saturation then no condensation takes place If intersection did occur, condensation could be avoided by adjusting the thermal gradient by changes in the position or value of the insulation, or by adjusting the continuity curve by changes in the permeability

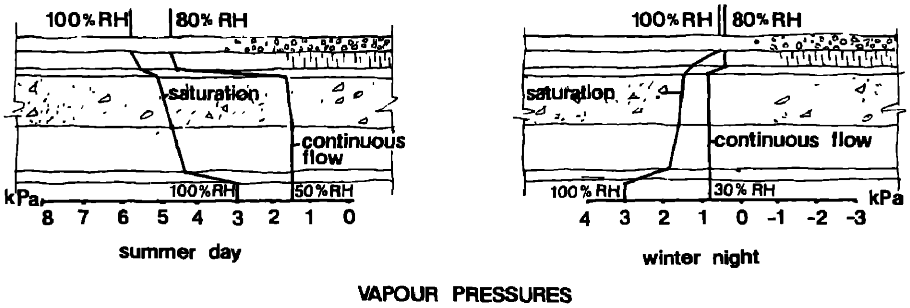


Figure 3.5.3 1-3
Saturation vapour pressure gradients, assumed roof construction

3.6 Building Fabric

3.6.1 Surfaces, Finishes and Colours

The influence of a surface upon heat transfer varies according to its emissivity and texture or configuration. Colour is also important because of its effect on surface emission

3.6.1.1 Emissivity

The emissivity of a surface at a given temperature equals its ability to absorb radiation from another body at the same temperature. In other words a material that is a good emitter of radiation is equally good as an absorber. The factor used to express this property is relative to the amount of radiation absorbed by a 'black body'. This 'black body' should not be confused with an actual surface coloured black. The black body referred to is one that emits the maximum radiation at any given temperature. It absorbs all the radiation which falls upon its surface and reflects none. The emissivity, hence absorptivity, of a black body has a value of 1.00

Regardless of temperature, surfaces are continually radiating and receiving radiation. However, no surface absorbs all of the radiation falling upon it, a proportion is always reflected, so that the emissivity values of all surfaces, in fact, are less than 1 00

For example, highly polished aluminum may have an emissivity of 0 04. This means that its absorptivity will also be 0.04 and its reflectivity 0 96

In contrast, non metallic surfaces such as black asphalt, brick and stone have emissivities of approximately 0 9, signifying their high absorptive and low reflective characteristics

Emittances for a number of typical surfaces are shown in Table 3.6.1.1-T_1.

3.6.1.2 Solar Radiation and Emissivity

It is evident from Table 3.6.1.1-T_1 that the emissivity of a surface at normal temperatures (10°C to 40°C) is not necessarily the same as its absorptivity for solar radiation. While black paint has the same emissivity as white paint in the normal temperature range its absorptivity for solar radiation is up to three times the value for white paint.

The whitewashing of Mediterranean houses each year indicates a traditional awareness of this. As Steadman observed,[1] the white exterior surface kept the interiors cool in summer and as the autumn rains washed off the spring-time painting a darker coloured surface was exposed which could absorb the warming winter sun

Recorded temperatures reached by dark slag roof surfaces have been as high as 80°C compared with 60°C for lighter coloured marble-chip surfacing.

Unfortunately, the protection afforded by colours against radiant solar heat again does not extend to heat loss; at normal temperatures it is not significantly affected by colour.

Another comparison of interest highlights the respective emissivities of highly polished aluminum and a white painted selective surface. At room temperatures the aluminum emits less than 5% as much radiation as the white surface but when exposed to solar radiation their absorptivities are almost the same. In other words, aluminum foil on a roof usually is no more effective as far as reducing heat load is concerned than a coat of white paint.[2] Table 3.6.1.1-T_1

indicates their different relationships for emissivity and absorptivity at various temperatures and their absorptivity for solar radiation

Bright aluminum foil has been utilized in construction as a thermal insulator because of its ability to reduce radiant heat transfer. To be effective it must be installed in an air space When applied as a surface layer to another insulating material and installed in wall or roof cavities, insulation will be provided against all three forms of heat transfer—convection, conduction and radiation
Refer also to **Section 3.6.4.2**—Cavity Construction.

RADIATION FACTORS OR EMISSIVITIES			
	Total Normal Emittance*		Absorptance for Solar Radiation
Surfaces	10°C to 38°C	538°C	
A small hole in a large box, sphere, furnace, or enclosure	0 97 to 0 99	0 97 to 0 99	0 97 to 0 99
Black nonmetallic surfaces such as asphalt, carbon, slate, paint, paper	0 90 to 0 98	0 90 to 0 98	0 85 to 0 98
Red brick and tile, concrete and stone, rusty steel and iron, dark paints (red, brown, green, etc)	0 85 to 0 95	0 75 to 0 90	0 65 to 0 80
Yellow and buff, brick and stone, firebrick, fire clay	0 85 to 0 95	0 70 to 0 85	0 50 to 0 70
White or light cream brick, tile, paint or paper, plaster, whitewash	0 85 to 0 95	0 60 to 0 75	0 30 to 0 50
Window glass	0 90	—	**
Bright aluminum paint, gilt or bronze paint	0 40 to 0 60	—	0 30 to 0 50
Dull brass, copper, or aluminum, glavanized steel, polished iron	0 20 to'0 30	0 30 to 0 50	0 40 to 0 65
Polished brass, copper, monel metal	0 02 to 0 05	0 05 to 0 15	0 30 to 0 50
Highly polished aluminum, tin plate, nickel, chromium	0 02 to 0 04	0 05 to 0 10	0 10 to 0 40
Selective surfaces Stainless steel wire mesh	0 23 to 0 28	—	0 63 to 0 86
White painted surface	0 92	—	0 23 to 0 49
Copper treated with solution of $NaClO_2$ and NaOH	0 13	—	0 87
Copper, nickel, and aluminum plate with CuO coating	0 09 to 0 21	—	0 08 to 0 93

*Hemispherical and normal emittance are not equal in many cases The hemispherical emittance may be as much as 30% greater for polished reflectors to 7% lower for nonconductors
**Absorbs 4% to 40% depending upon its transmittance

Table 3 6.1.1-T_1
Radiation factors or emissivities for a number of typical surfaces [3]

3.6.1.3 Surface Resistance

Resistance to the transfer of heat occurs between the surface of a material and the adjacent air. The value for this thermal resistance must be included in calculations for the overall air to air resistance of a structure, **Section 3.6.3.2.** Surface conductance is the reciprocal of this resistance.

As already stated, the heat transfer qualities inherently belonging to a surface are dependent on its emissivity and texture or configuration. When the area of a surface is increased, as, for example, by

corrugations, ribbing or similar configuration, its resistance is correspondingly reduced in comparison with a flat plane of the same material

Because heat flow is facilitated by upward, rising, convection currents the resistance of a horizontal internal surface such as a floor or roof slab is higher for heat flow down than it is for heat flow upwards.

External factors which affect the resistance of a surface, include the velocity of the air passing over it, its orientation, the air temperature and the temperature of neighbouring surfaces

In connection with the latter, when one surface is facing another of much lower temperature it will radiate to it. This can have important consequences as the resistance of the external surface becomes reduced, particularly during very cold, calm weather when the sky is clear and an exposed roof radiates to the atmosphere. Under such conditions the external surface temperature of a thin roof cladding can fall below the temperature of the adjacent external air.[4]

The modifying effect of surfaces, finishes and colour on the external micro-climatic environment of buildings is discussed in **Section 2.1.1.**

3.6.2 Thermal Conductivity

The thermal conductivity *k* of a building material is an expression of its ability to conduct heat

Conduction is one of the three mechanisms by means of which heat or thermal energy can be transferred from one region to another. It differs from the other two modes, radiation and convection, in that heat transference by conduction takes place through matter. In other words, conduction involves the transmission of kinetic energy within the molecular structure of materials. This occurs when materials are exposed to changes in air temperature or when materials at different temperatures are brought into contact.

Under such conditions thermal energy is transferred by the collision of vigorously activated molecules with less vigorous ones.[5]

Conduction is the most significant method of heat flow through an opaque solid Consequently, knowledge of the *k* factor of constituent materials is an essential prerequisite in order to assess the influence which the construction of a building has upon its heat transmission.

3.6.2.1 Heat Transfer

As postulated by the Second Law of Thermodynamics, the direction of heat flow is always from a warmer to a colder body. The amount of heat which will pass through a material by conduction from one surface to the other depends upon a number of factors. Heat transfer is directly proportional to temperature difference, to surface area and to the length of time during which the heat flow takes place. It is inversely proportional to thickness. The amount of heat transferred is also dependent on the rate of heat transfer, conductivity *k* of the particular material. In addition, the thermal conductivity *k* of materials varies according to their density, porosity and moisture content. It is also influenced by temperature but not significantly within the normal range of temperatures obtained in structural insulation.

As previously stated, *k* values of materials vary with their density. For example the rate of heat transfer through a material of high density such as rock is extremely high while that of rock wool, the same material in a fragmented condition, is much less. However there are optimum densities below which the *k* values of light weight materials will actually increase. This is a result of the increase in convection due to the large pockets of air which more than offsets the lower conduction.[6]

The rate of heat transfer of a light-weight material is also increased if it is packed or tamped to a higher density Figure 3.6.2.1-1.

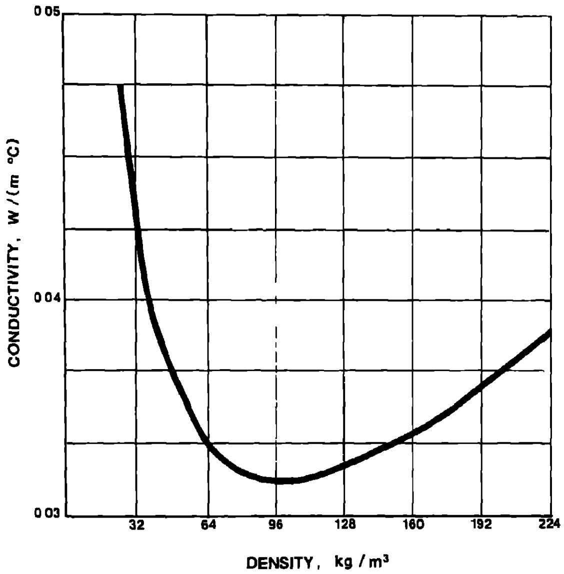


Figure 3 6 2 1-1
Variation of conductivity with density for typical fibrous material[7]

3.6.2.2 Moisture and Conductivity

The quantity of moisture held by a material can have a considerable effect on its *k* value. As water conducts heat more rapidly than air, the higher the moisture content, the higher will be the *k* value—and the lower will be its effectiveness as insulation. Rain penetration, high humidity within the building and condensation can all result in an appreciable amount of moisture being present in the building structure.

In comparing materials it is important to use *k* values that are related to appropriate moisture contents. Ideally, the conductivity values should be based on those that are likely to predominate in the materials when built into the structure

3.6.2.3 Surface Conductance of Materials

The co-efficients of conductivity and conductance which are used in the thermal analysis of construction represent the rate of heat transfer between the two bounding surfaces of a material or combination of materials. They do not represent the heat transfer from air on one side to air on another.

The film of air in contact with a surface offers a certain resistance to the passage of heat. Accordingly, the resistance of a material from one surface to the other is less than the resistance from the air on one side to the air on the other.

The surface conductance of a material is defined as the amount of heat transmitted from a surface to the air surrounding it, or vice versa. This conductance varies according to a number of factors including the nature of the surface, the velocity of air passing over it, the temperature of the surface, temperature differential between the surface and outside air and the direction of the heat flow.

3.6.2.4 Formulae

Thermal conductivity k is expressed as heat flow (in watts) through unit surface area (a square metre) of the material when a temperature difference of 1°C is maintained between opposite surfaces of a metre thickness of the material It may be expressed as.

$$k = \frac{W}{m^2} \times \frac{m}{°C} = W/m\ °C$$

Conductivities are not additive and appropriate formulae are required to calculate the combined effect of two or more materials.

In heat loss calculations it is often more useful to use the reciprocal of conductivity·

$$1/k = m\ °C/W$$

From this it is possible to determine the thermal resistivity value for the actual thickness of a material, or each material, being used in a building assembly. Note, the unit of thickness is the metre. Ref. also **Section 3.6.3** Insulation

3.6.3 Thermal Resistance

The thermal insulation value of a building material i e its thermal resistivity, is an expression of its ability to resist the transfer of heat It is the reciprocal of the conductivity factor k for the same material Since k is equal to W/m °C, thermal resistivity $1/k$ may be expressed as m °C/W For a description of thermal conductivity refer to **Section 3.6.2.**

The thermal resistance RSI of a material of given thickness is obtained by multiplying its thermal resistivity factor by its thickness in metres The thicker the material the greater its thermal resistance When several building materials are placed in parallel layers their total thermal resistance RSI may be obtained by adding together the resistances of the various material thickneses.

3.6.3.1 Rate of Heat Flow

The rate of heat flow through the total building fabric can be calculated as follows·

1. Obtain k (thermal conductivity value) for the materials involved. k=W/m °C
2. Obtain reciprocal of k to determine thermal resistivity value of each of the materials. $1/k = m \cdot °C/W$
3. Obtain thermal resistance of each material by multiplying its resistivity by its thickness in metres*. $RSI = m \times m \cdot °C/W = m^2 \cdot °C/W$
4. Obtain thermal resistances of surface air.
5. Add resistance of all materials, surface air and internal air spaces (if any) to obtain total thermal resistance.
6. Obtain reciprocal of total thermal resistance to determine thermal transmittance value U (ref. **Section 3.1.3** Heat Transmission) $1/RSI = U = W/m^2 \cdot °C$

*Note: The unit of thickness is the metre. If a material thickness is quoted in millimetres it must be converted to metres for the purposes of this calculation.

The co-efficient of thermal transmission (U) expresses the rate of heat flow (watts) through a unit area of a structure (square metres) when a unit difference of temperature (°C) exists between air on each side. This co-efficient is not additive, the overall heat transfer values of combinations of materials and assemblies must be obtained as described above. (Note watts = joules per second, i e rate of heat energy flow)

3.6.3.2 Equivalent Temperature Differential (ETD) Values

In order to determine heat gain through the opaque portions of walls and roofs, equivalent temperature differential (ETD) values are required in the calculations.[8] The ETD is defined as the difference between indoor and outdoor temperatures taking into account solar, convection and radiation heat flow into a space, according to geographic location. An allowance is also included for time lag.

3.6.4 Insulation

Light-weight construction has been the distinguishing characteristic of most buildings erected in the last half century Inherently, these light-weight structures have lacked the insulating properties provided by the brick or masonry mass of traditional heavy construction. This 'thermal mass' acted as a fly-wheel—the heat stored during the daytime was released overnight and the major diurnal swings in temperature which can be experienced in light-weight buildings were minimized considerably Table 3.6.4-T_1 gives U and time lag values for typical materials used in construction.

U AND TIME LAG VALUES			
Material	Thickness, mm	U, W/(m² °C)	Time lag, h
Brick (common)	100	3 5	2 50
	200	2 3	5 50
	300	1 8	8 50
Concrete (sand and gravel aggregate)	100	4 8	2 50
	200	3 8	5 00
	300	3 1	8 00
Insulating fiberboard	50	0 9	0 67
	100	0 5	3 00
Wood (fir, yellow pine, etc)	13	3 9	0 17
	25	2 7	0 40
	50	1 7	1 00

Table 3 6.4-T_1
U and time-lag values for typical materials used in construction [9]

Low density insulating materials have been developed in an attempt to compensate for this reduced mass in structure, as well as to supplement the insulating capacity of more conventional construction.

The enclosing fabric of contemporary building is usually a composite of materials, each layer of which is employed to perform a certain specific function. In a wall, for instance, one can distinguish layers of structural support, thermal insulation and surface coating. The interrelation of these layers has considerable effect on the physical characteristics of the building fabric.

COMPARISON: OUTSIDE INSULATION (WITH RAINSCREEN) AND INSIDE INSULATION.		
	Exterior insulation	Interior insulation:
Design	Supporting structure invisible	Supporting structure visible
Building Physics	All requirements easily met No problems in assessment of heat and sound protection Vented airspace closely follows outside air pressure All parts of structure exposed to similar temperature with only slight variation throughout year Thermal problems associated with connections of interior and exterior structural elements eliminated	Heat bridges pose problems at connections of interior and exterior structural elements, floor slabs and walls etc Exterior structural mass possible modifier of interior temperature
	Window frame attached to warm side of wall, edge cooling effect minimized	Window frame and sill on cold side of wall, substantial edge cooling effect
	Internal mass of building structures provides thermal 'flywheel' for heat storage	Likelihood of cracks in back-up and cladding due to thermally induced expansion and contraction
		Air leakages from this cause will result in condensation and degradation of wall materials
		All materials outside insulation will fall below freezing
Construction of Building	No special requirements Raw construction and completion simple to realize technically in traditional ways Complex building geometrics require expensive construction for heat protection Outside work requires scaffolding	Special requirements re heat bridges During raw construction insulating slabs must be built in these areas, danger of damage to insulating slabs
Weak points in Practice	Cavity must be kept clear Possible limitations in selection of outer facing to insulation	Possible incorrect placing of insulating slabs and creation of additional heat bridges

Table 3.6 4.1-T_1
Relative merits of outside insulation (with rainscreen) and inside insulation[10]

3.6.4.1 Location of Insulation

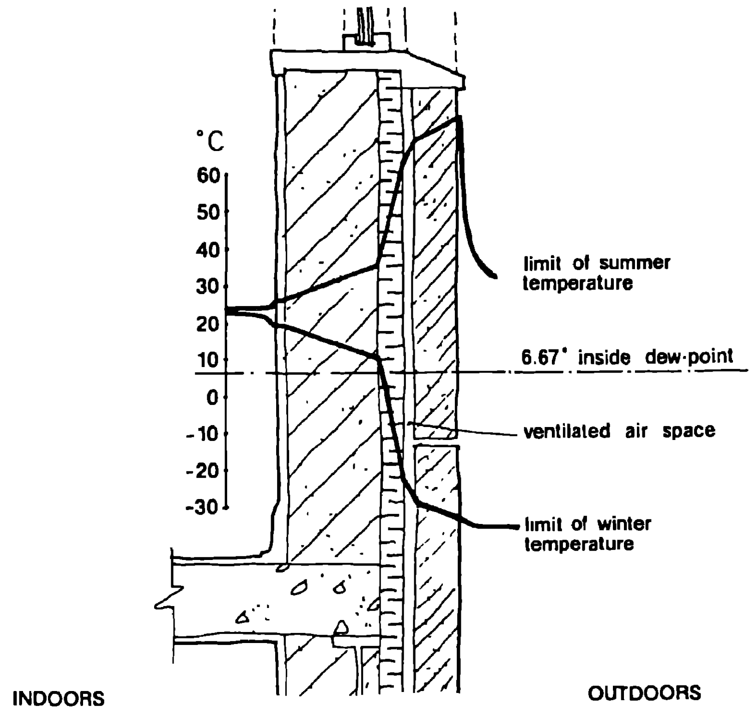
Where the layers of building materials are assembled parallel to each other, the determination of the particular location of each individual layer in the well warrants careful attention. The following identifies a number of possible conditions:

—homogenous wall (the supporting layer is also the insulating layer
—wall with outside insulation
—wall with coating insulation
—wall with core insulation
—wall with inside insulation.

Table 3.6.4.1-T_1 compares the relative merits of outside and inside insulation.

Figure 3.6.4.1-1, based on drawings prepared by NRC of Canada, indicates the location of the dew point in the two types of construction compared above in Table 3.6.4.1-T_1.

The other features summarized in the table will also be readily appreciated by reference to these drawings.



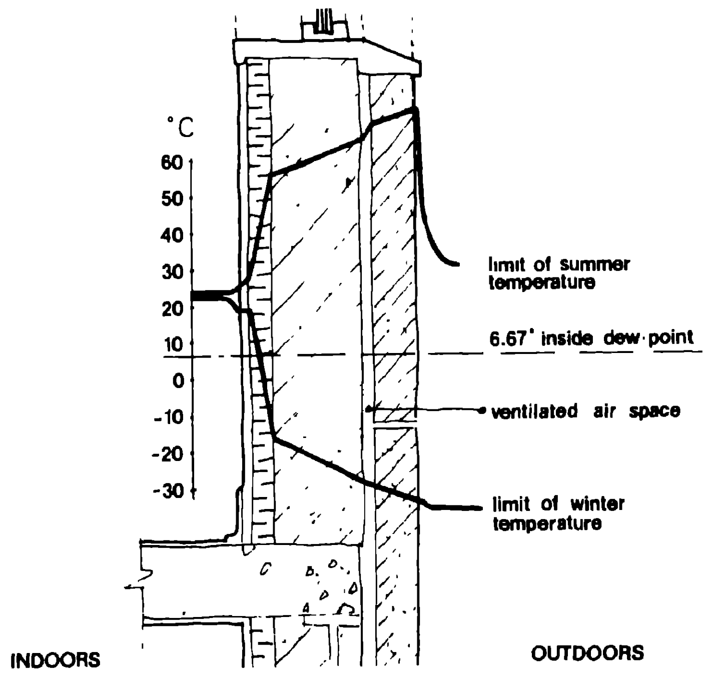


Figure 3.6.4 1-1
Wall sections, dew point locations

3.6.4.2
Cavity Construction

Heat flow from surface to surface across a cavity is effected by convection, radiation and conduction. The latter occurs if heat bridges are present. Critical in the design of cavities is their dimension, (if it is greater than 20 mm, convection currents will prevent further benefits), their enclosing surfaces and the ventilation rate, if any, **Figures 3.6.4.2-1, 2.** there must be a foil surface on one side[13]

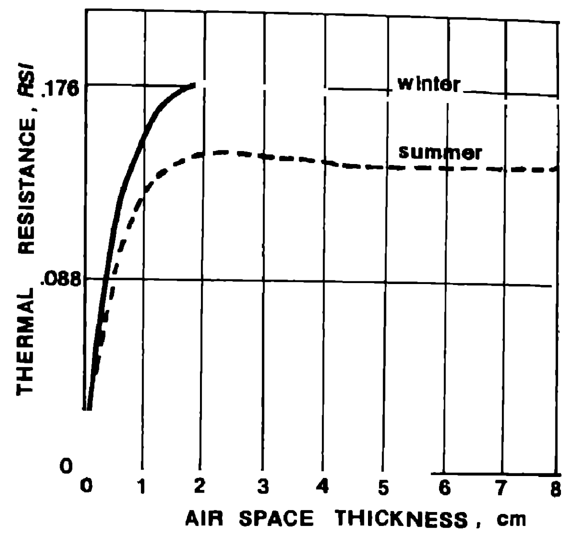


Figure 3.6.4 2-1
Variation in the thermal resistance of an air space with thickness[11]

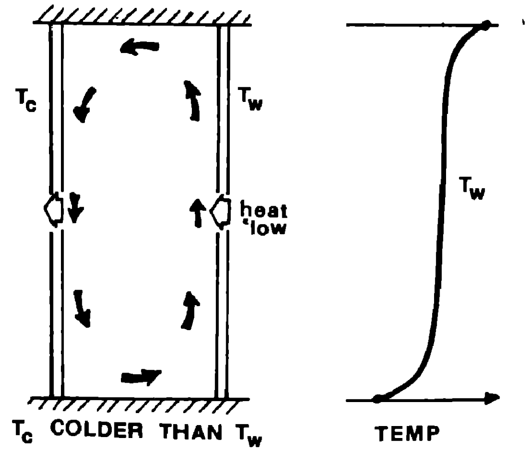


Figure 3.6.4.2-2
Effect of convection in an air space on the warm side surface temperature[12]

Mention was made in **Section 3.6.1.3** of the effect of convection currents on heat transfer. In a horizontal cavity when the heat flow is from below they tend to be vertical and when it is from above they are virtually eliminated as the warm air will be at the top layer. Insulation values will vary accordingly.

The effectiveness of bright aluminum foil as a thermal insulator in air spaces was noted in **Section 3.6.1.2.** When employed in a single unventilated cavity it reduced radiant heat transfer considerably and when used to divide an unventilated vertical cavity the two cavities

thus created will provide approximately double the insulation value It is necessary that each cavity be no less than 20 mm wide and there must be a foil surface on one side [13]

Aluminum foil can also be used to good effect in a horizontal cavity, 20 mm or more, where heat flow is downward, as in a roof space In such situations convection is virtually non existent and radiant heat transfer is the principal concern

3.6.4.3 Condensation

Particular care is required in the design of the building fabric to ensure that insulating materials are protected from the effects of condensation. Possible air movements through and within a wall are shown in **Figure 3.6.4.3-1**. The correct positioning of air, vapour, barriers is essential if loss of insulation values and degradation of materials are to be avoided

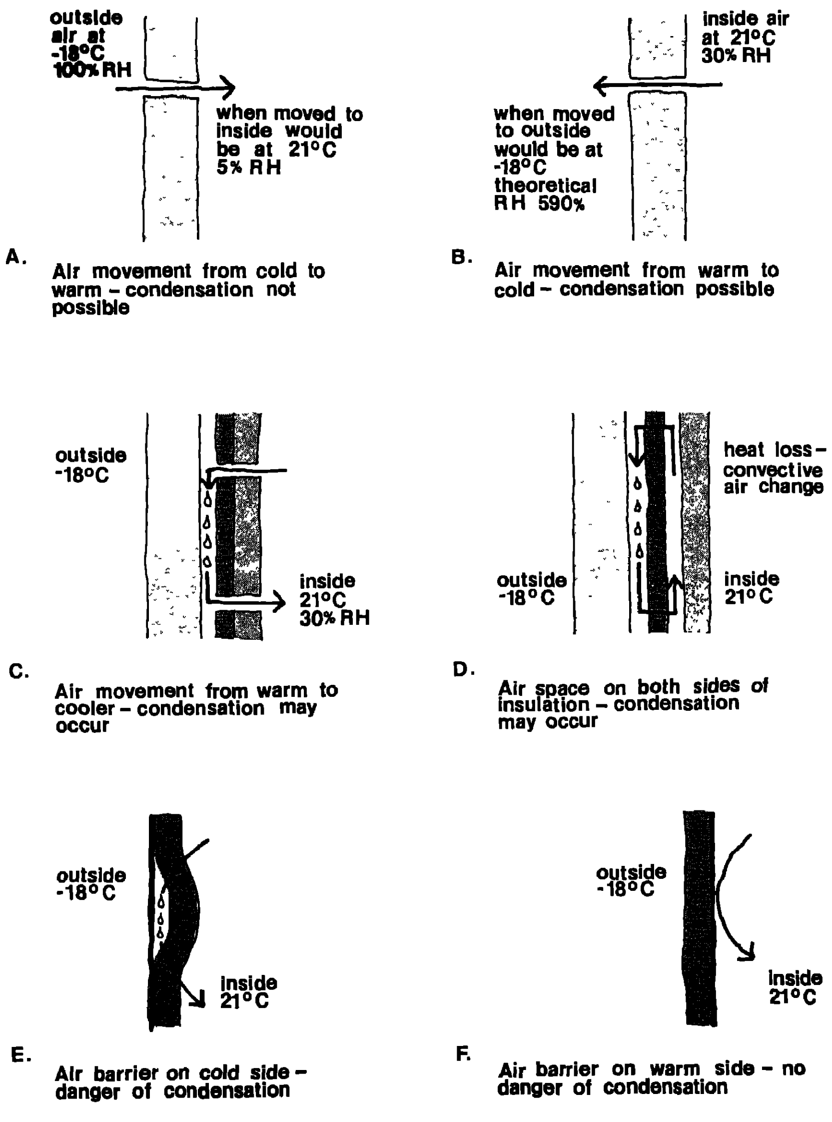


Figure 3.6.4.3-1
Effects of various possible air movements through and within a wall [14]

3.6.5 Glazing

For readers of this Handbook, the significant properties of glass are its ability to transmit light and its limited resistance to the transmission of heat At the present stage of manufacturing technology these two properties are mutually dependent

It is not yet possible to produce a glass which achieves some degree of heat rejection without affecting the amount of daylight which can be transmitted through it

This reciprocity is of obvious consequence in terms of energy conservation. Newly developed tinted or coated solar control glasses, for example, will reduce the cooling load in a building but their use could, under certain conditions, result in a net increase in the actual energy demand This would occur if additional lighting is required to compensate for the reduced amount of daylight reaching the interior A careful assessment therefore, of both light and energy transmission coefficients of these glasses is essential prior to selection

3.6.5.1 Heat Transmission

The process of heat transmission through glazing is a complex one

As solar radiation falls on a sheet of glass, some is transmitted directly through it, some is reflected and some is absorbed The amount absorbed is re-radiated back to the out of doors or into the room The precise proportions depend largely upon the movement of air at the surface of the glass

Under normal conditions approximately 30% of the heat absorbed by clear vertical glazing is dissipated internally With double sheets of the same material approximately 15% of the heat absorbed by the outer pane and 65% of that absorbed by the inner pane is re-radiated into the room

Ordinary clear window glass is virtually transparent to the normally incident short wave solar radiation, admitting close to 90% penetration This transmission of solar energy takes place without any change in wavelength However, once light of any wavelength has passed through the glass and has been absorbed in the structure and furnishings, the energy is trapped. The only escape for this long-wave energy emitted by the warmed surfaces and mass inside it is by convection and conduction The net result can be for the interior temperature to rise above that outside, entirely from solar transmission. This 'Greenhouse Effect'—the basis for flat plate solar collector design—results from the fact that glass is opaque to infra-red radiation

.1 **Condensation:** A graph of condensation prediction curves is shown in **Figure 3.6.5.1-1**. Double and triple glazing will help to reduce the incidence of condensation on the inside surface of the glass in winter and on the outside in summer

Exterior condensation will result when interior room temperatures are cooled to levels substantially lower than the outside air.

The graph may be used as follows.

Assume.	inside air temperature	=	20°C
	outside air temperature	=	– 10°C
	RH	=	30%
then:	required U value of glazing	=	5.2 or less to prevent condensation

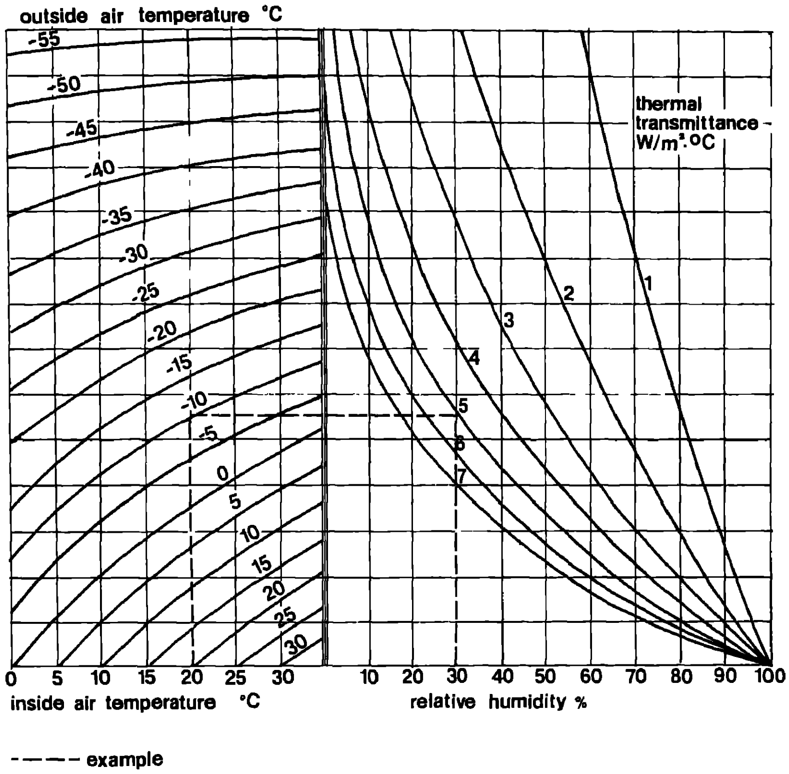


Figure 3 6 5 1-1
Condensation prediction curves[15]

3.6.5.2 Illumination and Heat Transfer

Artificial illumination can account for up to one third of the total energy consumption of commercial buildings, depending on the particular building design Additionally, the heat generated by electric lighting necessitates further energy usage and costs in the installation and operation of ventilating and cooling systems

Compared with artificial lighting, sunlight is a relatively cool light source It provides illumination of 90 lm/W–120 lm/W of total energy while fluorescent provides 40 lm/W–75 lm/W which in turn is two to three times as efficient as incandescent.

The potential of daylight as a source of illumination is quite apparent and is discussed in detail in **Section 3.14.4**. How can the building designer take advantage of this natural resource and at the same time, control heat transmission?

The amount of solar heat transmitted into a building through glazing is affected by the following factors·

—orientation
—area of glass
—type of glass
—absence or provision of shading devices

Types of glass are discussed below and discussion of the other factors listed will be found elsewhere in this Handbook, particularly **Section 4.9** Protective Elements.

3.6.5.3 Special Glasses

Glasses which have been developed in response to the problems posed by solar radiant heat transmission and heat loss include the following

—double and multiple glazing
—reflective glass
—heat absorbing glass
—glare control glass
—photochromic glass
—modification of clear glass

Figure 3.6.5.3-1 illustrates the properties of a number of types of glass presently in use

.1 **Double and Multiple Glazing**: This category comprises both clear and solar control glasses incorporated into sealed units Where clear glass is used throughout, beneficial improvement in thermal resistance is achieved with only minor effect on light transmission The width of the cavity affects the thermal transmittance of the unit as shown in **Table** 3.6 5.3-T_1. The optimum width is approximately 20 mm and air spaces wider do not give significantly improved performance A reduction may in fact take place when air space thicknesses exceed 100 mm as convection currents tend to develop in these larger spaces

THERMAL TRANSMITTANCE AND CAVITY WIDTH		
Air Space Thickness (mm)	Double Glass *RSI*	Triple Glass *RSI*
6	0 29	0 43
13	0 32	0 49
19	0 33	0 52

Table 3.6.5 3-T_1
Comparison of *RSI* values for double and triple glazed clear glass at different air space thicknesses

The values in **Table** 3.6.5.3-T_1 are for the glazed part of the window and do not account for transmission through the frame. The heat-bridge effect through metal framed windows can increase the average value appreciably unless thermal breaks are incorporated

Where used in combination, the heat absorbing glass is usually placed on the outside.

Sealed insulating glass units are subject to expansion and contraction due to changes in atmospheric pressure and temperature. Provision must be made in their installation to accommodate this.

.2 **Reflective Glass**: Typically, this consists of one light of metallic coated glass laminated to another light during manufacture The laminating process is necessary in order to protect the reflective, metallic film which is too delicate to be exposed to weather or cleaning.

In addition to its highly reflective quality, the solar heat transmission of this glass in a sealed unit with a clear type is reduced to approximately 20%. However there is also a substantial loss in light transmission which could be as low as 15%. (The light transmission for a single sheet of clear glass is 88%).

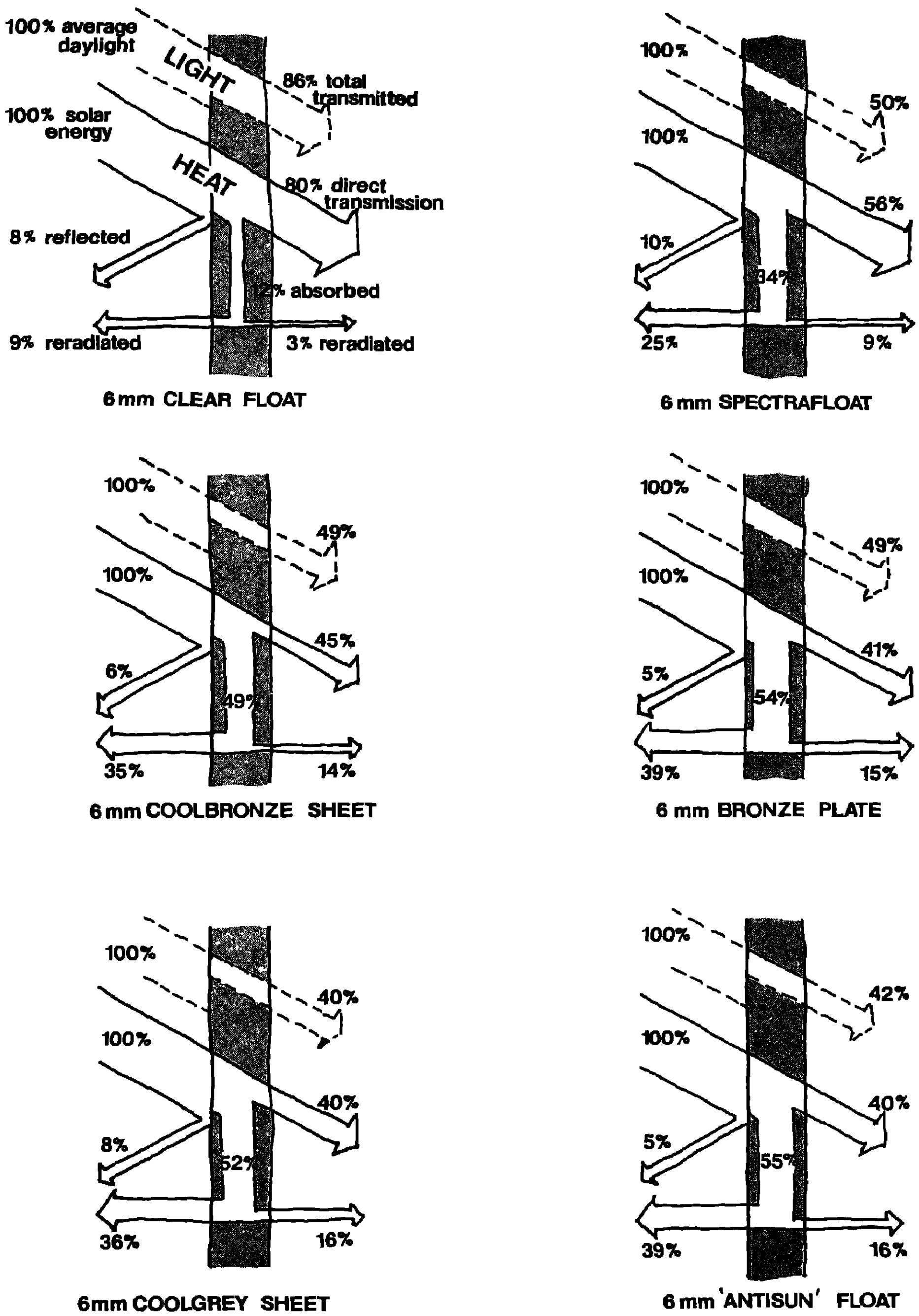


Figure 3.6.5.3-1
Properties of various types of glass[15]

The metallic surface of reflective glass in sealed units provides improved thermal insulation against heat loss by reducing the radiative transfer of heat across the cavity. Unfortunately, this property operates in summer to increase the retention of any solar heat which has penetrated into the building.

Also, reflection of the summer solar radiation is obtained at the expense of the desirable winter sunshine which is reflected just as effectively.

.3 **Heat Absorbing Glass**: This type of glass is available in a variety of colours but it is used principally in the bronze, grey and green ranges Dependent on manufacture, the colour can vary in direct proportion to the glass thickness Where changes in thickness are contemplated the effect on facade appearance must be considered

Absorption is in the region of 50%, the percentages for light and total solar energy transmission being slightly lower Absorptive glasses reflect only a small percentage of solar radiant energy but their effectiveness is in the amount of heat which is absorbed and re-radiated to the outside

.4 **Glare Control Glass**: As stated earlier, glasses are not selective in their control of the visible and invisible spectrum Accordingly reduction in visual glare from large areas of bright sky will also result in a similar reduction in transmission of the infra-red As glare and solar heat tend to co-exist, this property of glass can be used to advantage The result has been the development of dual-purpose glasses, body tinted or surface coloured, which in recent years have been used extensively to meet these requirements Originally of plate glass, less expensive types are now available

.5 **Photochromic Glass** [16]: These glasses, now being developed, contain constituents which vary in intensity according to the amount of light falling upon them One type contains silver halide particles which dissociate in strong sunlight producing a darkened, silver body In shade, the halides reform They have good potential for the control of glare Their absorption effect does not extend much beyond the visible spectrum—which contains approximately 50% of the sun's radiant heat energy, except when the sun is low in the sky

Another glass with similar responsiveness to light intensity consists of two laminations with a plastic interlay which turns milky as the light increases Light and heat transmittances of approximately 40% are claimed

.6 **Modification of Clear Glass**: A major weakness of surface applications to existing clear glass installations is their vulnerability to scratching during cleaning, from weathering or otherwise

—**Special Lacquers**: These may be difficult to apply smoothly They can usually be stripped and removed or replaced, as required

—**Surface Films**: Once applied to the glass, these films are difficult to remove Alternatively they can be installed on the outer face of window blinds

The manufacturers claim that tests show glass protected with surface films is more resistant to shattering. Reflective films give windows a mirror like appearance from the outside and reduce the penetration of ultra violet rays by approximately 80% Typical heat balance diagrams for clear glass and glass with an 18% visible reflective film are shown in **Figure 3.6.5.3-2**.

.7 **Shading Coefficients**: A comparison of shading coefficients for several types of glazing treatment is given in **Table 3.6.5.3-T$_2$**. The guide provides a table of shading factors for other devices. Shading coefficient values indicate the ratio of solar heat gain through a glazing unit to solar heat gain through a single light of double strength 3 mm sheet glass under the same set of conditions.

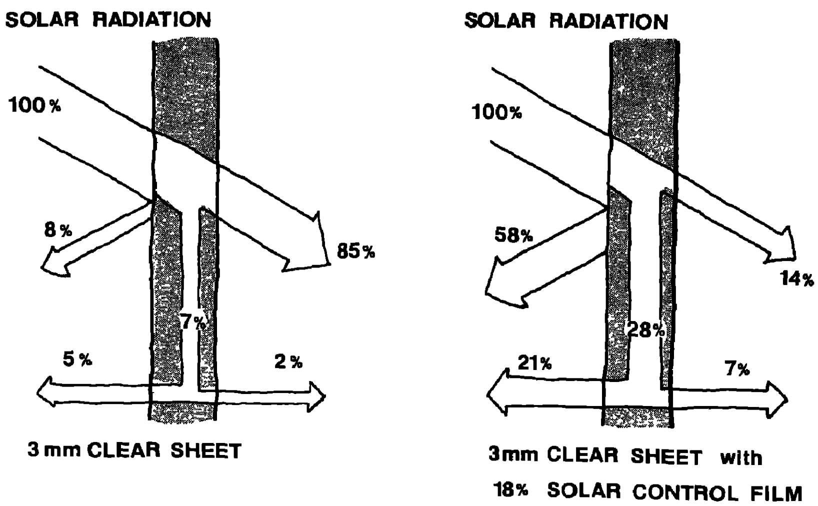


Figure 3 6.5 3-2
Solar radiation heat balance for 4 p m , July 21st, 40° north [17]

COMPARISON OF SHADING COEFFICIENTS	
Type of Glazing Treatment	Shading Coefficient
Single DS window glass	1 0
Inside medium venetian blind fully drawn	0 65
Plastic coating on glass lightly coloured	0 70—0 60
6mm Bronze plate glass	0 65
'SCOTCHTINT' A-18 Surface film	0 25
'SCOTCHTINT' A-33 Surface film	0 42

Table 3 6 5 3-T_2
Comparison of shading coefficients for several types of glazing treatment [18]

3.7 Solid Waste Disposal Systems

The following pages in **Section 3.7** present a review of the most up to date solid waste handling technologies, their status and the contributions they can make to solving waste disposal and energy problems

3.7.1 General Categories

Municipal solid waste disposal is an integral part of town planning and presents an exciting challenge and opportunity to the architect and engineer in the area of energy and resource recovery

Municipal solid waste (MSW) is defined as household and commercial (but not industrial) refuse, as well as refuse from alleys, streets, trees, landscaping, parks, beaches, etc. It is heterogenous, containing paper, food waste, vegetation, metal, glass, cloth, plastic and other components Its composition will vary continuously, but somewhat predictably The current daily average MSW quantity per person is 1 5 kg to 1 7 kg. Resources that may be recovered from MSW include ferrous metals, aluminium, paper, organic materials, glass and fuel Heat generated in the processing may also be recovered

Municipalities are aware that landfill sites are increasingly difficult to find, particularly near large cities, and industries are being forced to reduce their energy consumption due to the high cost. Consequently, there is a merging of the interests of the two parties and recent trends in MSW disposal reflect this

The complexity of MSW energy and resource recovery projects becomes apparent when one considers the number of participants who, of necessity, are involved They include federal, provincial and municipal agencies, private waste collection firms, processing plant operators, purchasers of energy or recovered resource materials, boiler plant owners and operators, secondary market dealers, financial institutions, etc whose coordinated activity is essential for the implementation of most municipal waste handling facilities

These projects aim to be profit-making entities and for their success depend on how they can meet market requirements with minimum assistance from government

3.7.1.1 Available Options

Today, the options available for energy and/or resource recovery include:

—refuse derived fuel (RFD) manufacturing
—incineration
  mass burning
  semi-suspension (shredded) burning
  controlled air burning
  fluidized bed
—pyrolysis.

Characteristics of these systems are included in **Table** 3.7.1.1-T_1.

3.7.1.2 Unit Sizing and Optimum Number of Units

The choice of unit size and the number of units that should make up a facility is dictated by:

—the equipment that is available from manufacturers
—the overall cost of a single or multi-unit installation

—the provision that is to be made to take care of plant breakdown or maintenance outages.

ENERGY RECOVERY OPTIONS					
Option	General Description of Process	Preparation of Refuse	System Requirements	Residue from Process	Remarks
Refuse derived fuel	treatment of refuse to produce a fuel	shredding plus separation of ferrous metals, aluminum, glass, organics and paper	usually a cyclone and baghouse	RDF	
Incineration Controlled air	combustion of refuse in a multichamber system using controlled reducing and oxydizing atmospheres	none generally required for normal domestic refuse, bulky items such as stoves and refrigerators to be removed	no additional equipment normally required to meet environmental standards	metals, sterilized ash and slag	will not readily accept sewage sludge
Mass burning	combustion of refuse in the basically as-received condition usually on travelling grates in water wall or water tube boilers	shredding or crushing of bulky items such as tires and carpets, recommended	precipitator or flue gas scrubber	non-petrus-cible ash with metals and slag	can be designed to accept prepared sewage sludge
Shredded burning	combustion of refuse that has been reduced to less than about 25 mm in size in furnaces equipped with travelling grates, the prepared fuel usually being injected into the furnace by way of wind swept refuse entry ports	removal of metals and glass, shredding to small size for wind swept injection to furnace	precipitator or flue gas scrubber	fine sterilized ash	suitable for burning sewage sludge
Fluidized bed	combustion of refuse in a hot aerated volume of inert granular material, usually sand	removal of metals, glass and extraneous dust, shredding of large items to about 3-inch size	precipitator or flue gas scrubber	fine sterilized ash	suitable for burning sewage sludge
Pyrolysis	the reduction of waste by destructive distillation in a controlled atmosphere	none generally required except for the removal of bulky items	precipitator or flue gas scrubber	fine sterilized ash	system will accept sewage sludge

Table 3.7.1 1-T$_1$
General characteristics of energy recovery options

A single-unit installation usually gives lowest capital cost, but does not have the flexibility of a multi-unit plant with respect to maintenance and expansion.

The range of capacity of single units of equipment commonly avail-

able for the different energy conversion options being considered are shown in Table 3.7.1.2-T_1.

EQUIPMENT CAPACITY RANGE	
Alternatives	Capacity, t/d
Refuse derived fuel, RDF	no limit
Incineration	
—mass burning	15 to 1 000
—shredded burning	200 to 1 200
—controlled air	2 to 100
—fluidized bed	2 to 600
Pyrolysis	5 to 1 000

Table 3.7 1 2-T_1
Capacities of commonly available solid waste disposal systems

3.7.1.3 Energy-Related Benefits

Solid waste disposal systems reduce land fill requirements, they minimize environmental problems by producing a sterilized ash and permit the recovery of marketable materials such as paper and ferrous metals Other benefits which can be derived and which are of particular interest to readers of this Handbook are the following
—a solid (RDF), liquid or gaseous product which can be sold as a fuel
—steam or hot water for heating of residential, commercial, institutional and industrial complexes
—steam for operation of turbine-generators to produce electricity

3.7.2 Resource Recovery and Refuse Derived Fuel (RDF)

The need to find efficient ways of solid waste disposal in face of the rapidly increasing landfill shortage and costs, and the existence of potential markets for the resource material and the fuel contained in the refuse, has resulted in a number of resource recovery and RDF projects

The major objective is to convert the MSW into a solid fuel suitable for burning

The ultimate success of such projects depends on technical viability and economic constraints such as market conditions, legislative changes, environmental concerns and the risks in facility construction and operation. Initiation of RDF and resource recovery projects throughout the world is hindered by the lack of relevant cost statistics which are required for assessment of economic viability.

3.7.2.1 Plant Description

A full scale demonstrator facility began operating in Toronto recently and it is hoped that careful monitoring will help to fill some of the gaps. A description of the plant follows and the flow diagram is illustrated in **Figure 3.7.2.1-1**.

The first stop for refuse is at the transfer station. Here electronic scales weigh both incoming and outgoing trucks. Any excess waste beyond the eight hour shift capacity of the plant (270 t) is compacted and trucked straight from the transfer station to the landfill

Waste bound for recovery is conveyed to a primary shredder which

reduces the maximum material size to 152 mm It is then subjected to two stages of air separation, passes through a cyclon and discharges to a density classifier and is finally dried and stored before being compacted and sold as RDF on the supplementary fuel market RDF can also be produced as a pelletized or briquetted fuel, however, most suppliers prefer the light fraction RDF

The remaining heavy portion of the waste (40%) undergoes further treatment to recover the marketable resource materials such as ferrous metals, glass, aluminum and organic material for use in compost The final unrecoverable portion of waste is disposed to landfill

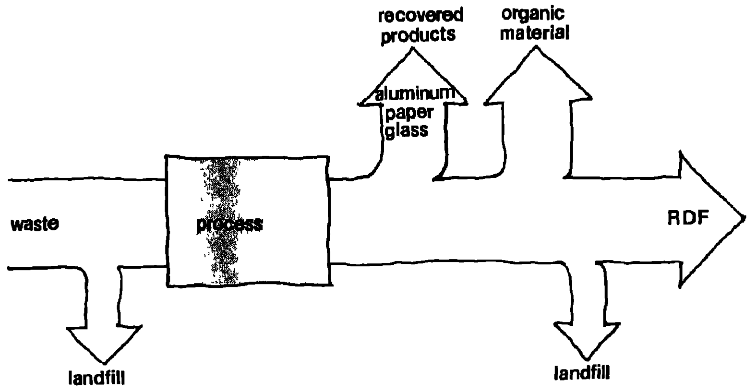


Figure 3 7 2 1-1
Resource recovery and RDF flow diagram

3.7.2.2 RDF as a Supplemental Fuel

RDF can be used as a supplementary fuel to conventional fossil types However, the use of RDF entails direct costs and risks Factors to be considered include whether the boiler to be modified is coal or oil-fired, whether the pollution control and ash handling equipment is still usable, risk of boiler tube corrosion, loss of combustion efficiency, etc. If the boiler site is distant from the RDF manufacturing plant, the unit value of the fuel may have to be discounted to allow for the transportation cost All the above indicates that applications under consideration can present different conclusions.

RDF can also be used in heat recovery systems other than boilers For example, a cement company in Ontario anticipated a saving of 40% on the coal normally used by the supplementary burning of RDF in their rotary kilns

3.7.3 Incinerators

Although large incinerator installations have been operating since the turn of the century in some countries, the greatest developments in the design of incinerators with energy recovery and environmental control have taken place in Europe over the past twenty years. More recently, interest in this field has also increased in Japan and North America.

There are many examples of steam producing incinerators in the U S and Canada:

—Montreal, Quebec

—Quebec, Quebec
—Hamilton, Ontario
—Harrisburg, Pennsylvania
—Chicago, Illinois
—Nashville, Tennessee
—Saugus, Massachusetts
—Norfolk, Virginia

Regardless of the firing method, their common objective is to ensure complete combustion of the MSW while at the same time preventing the formation of objectionable slab deposits

3.7.3.1 Emissions and Ash

It is a characteristic of incinerators to have high particulate emission in the flue which necessitates the use of high efficiency dust collection equipment which usually takes the form of electrostatic precipitators

In most incinerators, ash handling is combined with a material recovery process. In the typical incinerator, unburned residue falls off the last grate into a quench tank, from which it is conveyed to a trommel screen which separates the smaller than 50 mm material on to a vibrating conveyor that carries them past a drum magnet The smaller ferrous material drawn off by the magnet is collected and sold to the scrap iron dealer The oversize from the trommel screen and the non-ferrous 50 mm or smaller glassy aggregate, less than 5% by volume of the original refuse stream, are disposed via the landfill

3.7.3.2 Economies

In order to gain an insight into the overall economic feasibility of an incinerator plant as an energy producer, the data shown below summarizes basic costs and process parameters

BASIC COSTS AND PROCESS PARAMETERS	
Incinerator Plant, Saugus, Mass	
Design capacity	1500 t/d MSW
Investment	$50 million/a (1975)
Year of annualized cost	1976
Annualized capital cost	9 86/t MSW
Operating cost	$10 9 t MSW
Total annualized cost	$19 95/t MSW
Energy output	2070 kg/t MSW

Table 3.7 3 2-T_1
Economic feasibility of an incinerator plant

Although the use of steam at the Saugus plant is for electrical power generation, this, unfortunately, is not the general rule. In the case of utilities, economic considerations usually dictate the use of high steam pressures 413 400 kPa/s and high super-heat temperatures (510°C minimum). There are relatively few incinerators designed capable of meeting these requirements and these plants are found mainly in Germany. In most cases, therefore, the incinerators in North America must serve a market for steam produced at a lower pressure level such as district heating and process heating. The economic justification for most incinerators

cannot be based alone on the steam market, but must rely on other sources of revenue such as tipping fees or resource recovery These tipping fees can vary anywhere from $2/t to $15/t in congested metropolitan areas, depending on the proximity and capacity of the nearest landfill The foregoing underlines the dual role of incinerators in regard to solid waste disposal and energy production

Whether one or both of these functions can justify the capital and operating costs of the incinerator must be the subject of thorough market analysis and obviously each case must be studied individually

3.7.3.3 Types of Incineration

The principal features of the four types of incineration referred to earlier are as follows

.1 **Mass Burning**: This type of incinerator is the most common and usually burns untreated refuse on a travelling grate. In some installations, large items may be shredded or sheared with a supplemental system to remove ferrous materials

The Saugus facility has been producing steam for three years. This plant is representative of the modern concept of incinerators and the sequence of this operation is shown on the simple flow diagram **Figure 3.7.3.3-1**

The burning method employed results in a large furnace volume in which the high temperature combustion necessary for efficient incineration takes place with minimum excess air utilization.

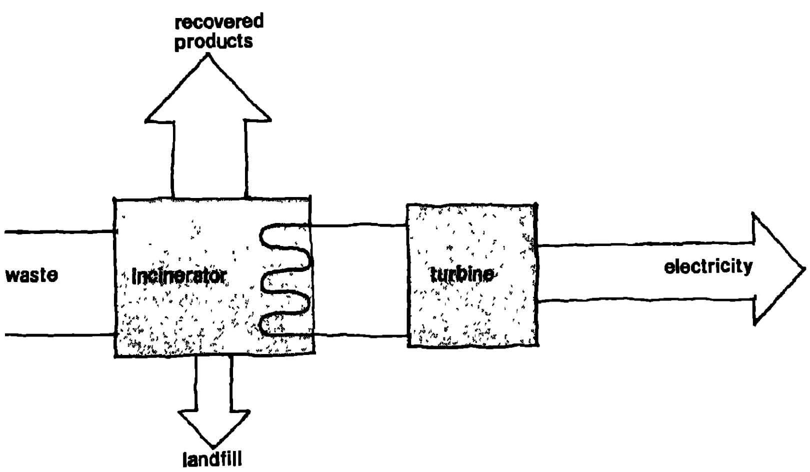


Figure 3 7 3.3-1
Incineration flow diagram

.2 **Semi-Suspension Burning (RDF)**: Although not as common, this method has gained popularity in recent years It has been used widely in the past to burn bark and other fibrous wastes Its advantages are that coal can be used as an alternate fuel and it provides efficient energy recovery while corrosion is minimized.

This type of boiler is a variant of the waterwall incinerator. RDF is fired in a suspension or spreader stoker waterwall boiler Higher pressure and temperature, closer combustion control and more efficient material recovery of non-combustibles can be attained than in the incinerator which burns raw waste. However, these

BASIC COSTS AND PROCESS PARAMETERS		
Item	Milwaukee, Wis	Hempstead, N Y
Initiation date	1975	1978
Process	RDF	RDF 100% fired boiler
Design capacity	1000 t/d MSW	2000 t/d MSW
Capital cost	$18 million (1977)	$73 million (1978)
Year of annualized costs	1977	1975
Annualized captal cost	$7 09/t MSW	$11 05/t MSW
Operating cost	$9 75/t MSW	$10 16/t MSW
Total annualized cost	$16 84/t MSW	$21 21/t MSW
Energy output	$6\ 33 \times 10^6$ kJ/t MSW	640 kW h/t MSW

Table 3.7.3 3-T_1
Typical cost figures for RDF fired units

features must be weighed against the higher capital cost for preparation of the RDF

.3 **Controlled-Air Burning**: This process uses an incinerator and heat exchanger system and is more suited for smaller communities and plants The controlled-air incinerator utilizes a two stage combustion process Solid wastes are loaded into the feed hopper from the charging floor using a small tractor The charge is transferred into the distillation chamber by a hydraulically-operated ram where the wastes are volatilized by partial oxidation Ignition is usually by gas fired pressure. In the secondary combustion chamber, one or more burners and additional air are provided for warm-up and to maintain the temperature necessary for complete combustion of all volatiles in the combustion gases From the after-burner chamber the hot gases are directed by dampers, either directly to the atmosphere through a stack or through a waste heat boiler to a secondary stack No auxiliary pollution control devices are required

.4 **Fluidized Bed Process**: Fluidized bed combustion is a method of burning a fuel in an inert bed of materials which is maintained in a fluid state by the upward flow of high velocity combustion air For start-up, a burner, fired by conventional fuel, heats the fluidized bed to the ignition temperature of the waste material When ignition temperature is reached, the burner is shut off and the feed material admitted from above the bed Gases resulting from combustion are passed through a cyclone where entrained particulate matter is removed For heat recovery, these gases are passed through a waste heater boiler and then to a stack via a wet scrubber

In some systems, the heat recovery system is an integral part of the fluidized bed unit. Large non-combustible products settle through the fluidized bed and are withdrawn through a hopper in the bottom

This system has the advantage it can burn a wide variety of difficult materials, often without modification, including municipal wastes, sludge, wood wastes, etc. High sulphur fuels can be burned without emission problems by replacing the sand bed with limestone which produces calcium sulphate during combustion

Fluidized bed systems have not been without their problems although a unit using wood wastes at Great Lakes Paper in Thunder Bay, Ontario appears to be operating with considerable success Interest has accelerated in the last year in the U S and U K due to the potential of burning high sulphur coal in fluid bed systems. Further technology developments and an increasing number of manufacturers in the field will no doubt rapidly increase the quantity of operational units

3.7.4 Pyrolysis

Pyrolysis or destructive distillation of MSW is a type of energy recovery process which converts refuse to fuel gas of low heat content It is fundamentally a burning process where the oxygen present is less than sufficient for full combustion.

3.7.4.1 Process and Product

Unsorted MSW without pretreatment is fed into the top of a vertical reactor called a gasifier where an incomplete combustion takes place with the aid of high temperature (1100°C) air which is preheated by oil or natural gas As the hot gases rise through the refuse, the latter slowly descends and is removed from the bottom of the gasifier as a molten slag which, after quenching, is removed by conveyor Ferrous materials are magnetically separated The gases, generated by pyrolysis, leave the gasifier at 480°C–550°C and have the composition shown in **Table 3.7.4.1-T_1**.

GAS COMPOSITION	
Compound	Mole, %
Carbon dioxide	9 4
Nitrogen	64 1
Oxygen	4 9
Carbon monoxide	9 4
Hydrogen	10 5
Methane	1 3
Ethane	0 2
Propane	0 1

Table 3 7 4 1-T_1
Composition of gases generated by pyrolysis

The heating value of the gas on a dry basis can vary from 4100 kJ/m^3 —15 400 kJ/m^3 depending on process characteristics It is estimated that an energy content of 8×10^6 kJ/t of MSW feed can be recovered, not including the auxiliary fuel input

If the pyrolysis plant produces steam or hot water, the gases generated are fed into a secondary combustion chamber from where the products of combustion heat a waste heat boiler before they are discharged to atmosphere through a scrubber If, however, fuel gas is the ultimate product of the plant, an electric precipitator or scrubber removes the particulate before the gas is compressed and transported to the user.

The gas produced by the pyrolysis plant could be utilized in the following ways:

—compressed and piped directly to nearby industrial customers
—upgraded to pipeline quality by methanation or other refining process
—used to generate electricity either directly in a nearby gas turbine/generator or in a conventional steam power plant
—converted to other products, such as methanol, in a catalytic process.

3.7.4.2 Summary

At the present time, pyrolysis is generally considered as unproven technology with a more costly method of MSW energy conversion than RDF manufacturing or incineration. Also, the sale of the gas produced is usually restricted to nearby utility and industrial markets because of its high carbon monoxide content, low heating value and small economic transport radius

Particulars of some pyrolysis projects are shown in **Table 3 7.4.2-T$_1$**

BASIC COSTS AND PROCESS PARAMETERS			
Item	**South Charleston, W Va**	**Baltimore, Maryland**	**Orchard Park N Y**
Process	PUROX	LANDGARD	ANDCO-TORRAX
Design capacity	200 t/d MSW (experimental)	100 t/d MSW	75 t/d MSW (demonstrator)
Capital cost	$15 million	$30 million	$2 2 million
Energy output	gas 566 kL/t MSW refuse 1 100 kJ/m^3 MSW ferrous metal recovery sterile granular residue	steam	steam (operation discontinued)

Table 3 7 4 2-T$_1$
Typical costs of several pyrolysis projects

A number of pyrolysis projects have been in operation over the past few years with a varying degree of success

The South Charleston system has experienced marketing difficulties and the Baltimore facility has been purchased by the City from the developer with a number of modifications being planned or already installed [1] The Andco system is having success in Europe with facilities operating in Luxembourg and Grasse, France and facilities approaching startup in Frankfurt, Germany and Cretel, France

3.7.5 Anaerobic Decomposition

This method of energy recovery from MSW makes use of landfill as a waste disposal method without submitting the waste material to any external process Anaerobic decomposition is defined as a bacterial process which takes place in the presence of organic material devoid of oxygen.

Such condition may prevail in existing landfills where the raw refuse is buried deep enough (6 m minimum) to prevent the infiltration of air into the waste system. In the absence of oxygen the MSW is decomposed by the anaerobic bacteria which results in the

generation of a gas containing methane and carbon dioxide in amounts of 55% and 45% respectively.

A completed landfill has an energy producing lifespan of around 10 years, after which the recovery operation is uneconomical because of the diminished methane content of the gas

3.7.5.1 Process and Product

Gas is removed from the well through piping and discharged to a purifying plant or to a direct fired gas engine During rains and winter periods methane content decreases by approximately 5%

The industrial utilization of this process is still in the experimental stage and solutions to the following problems are being studied·

—low energy yield
—temperature sensitivity of the anaerobic digestion process
—corrosiveness of the raw gases

Should this process become competitive with other waste energy recovery processes, it has the potential not only to obtain energy from existing landfill sites but to initiate mechanical digestion installations in large storage tanks leading to more efficient fuel gas recovery

3.7.6 Financing

Once the optimum energy conversion process for the given conditions has been selected financing and ownership require consideration. An energy recovery plant is in competition with other energy producing systems and must be carefully financed and operated to stay in competition

3.7.6.1 Examples

Financing can be provided from either the public or private sector.

.1 **Hempstead, New York**: Here arrangements were made with a private company to build and operate a 2000 t/d facility. By going with a private firm there was no capital involvement on part of the town, only a per tonne dumping fee Because of difficulties in the bond market, financing was arranged through a consortium of private insurance companies To satisfy the lenders long term contracts were arranged for the sale of electricity, aluminum and glass The Town of Hempstead receives about 15% of the proceeds from the sale of recovered material and 40% of the proceeds from the sale of power

.2 **Hooker Chemical Corporation**: This 2200 t/d energy recovery plant under construction at Niagara Falls, New York, is scheduled for completion in 1980. Permission to sell industrial development bonds was obtained through the Niagara County Industrial Development Agency For an energy-from-refuse plant, tax exempt bonds, which are attractive because of the low interest rates, are available However, this tax-exempt status extends only to the point of steam discharge from the boiler.

Beyond this point, the project was considered to be a commercial venture by the IRS, not a benefit to the public For financing equipment downstream from the plant, such as the turbine-generators, Hooker decided in favour of a lease-back plan through an independent investment agency

3.7.6.2 Canadian Government Assistance Programmes

To assist private industry in Canada to undertake energy recovery projects, several government programmes are available One or more of them may be applicable to a particular project, depending on its content and purpose These programmes are described in Table 3.7.6.2-T_1.

In addition to these federal-sponsored programmes, there are cost sharing agreements in many provinces between the federal and provincial governments to provide assistance to energy recovery projects, including the use of solid wastes Some energy recovery projects may also be eligible for low interest rate loans from provincial institutions where there is some potential for a return on investment

GOVERNMENT PROGRAMMES		
Programme	**Particulars**	**Sponsor**
Industrial Energy Conservation Research and Development Program (IERD)	cost sharing grants of up to 50% for development of more competitive energy efficient processes	Department of Industry Trade and Commerce
Forest Industry Renewable Energy (FIRE)	taxable payments of up to 20% off capital costs for new facilities to use hog fuel saw dust or wood waste or pulp mill waste liquor for energy	Department of Energy Mines and Resources
Biomass Energy Loan Guarantee	loan guarantees up to ⅔ of total capital cost with ceiling of $30 million per project primarily for substitution of forest or municipal wastes to generate heat and electricity	Department of Energy Mines and Resources
Energy from the Forest (ENFOR)	100% of costs for research, development and demonstration projects related to biomass production and conversion	Canadian Forestry Service Fisheries and Environment Canada
Energy Conservation Tax Incentives	two year write off on equipment which uses municipal, industrial or wood waste to produce heat or electricity	Revenue Canada

Table 3 7 6 2-T_1
Government programmes to encourage energy recovery projects

3.7.7 Conclusions

Overall performance of waste disposal/recovery facilities must be evaluated on an individual basis Conclusions drawn on similar installations but at different geographic locations might show few similarities However, in the following summary, comments are presented which relate to all waste disposal/recovery systems, regardless of type

Although the primary function of the systems which have been described is that of waste disposal, for the purpose of this text we have emphasized the energy recovery aspect It is not intended to rate the importance of one function versus the other, but rather to indicate the extent to which these systems help to resolve the problems of energy and/or disposal.

3.7 Solid Waste Disposal Systems

3.7.7.1 Volume Reduction

By burning solid wastes, the volume of the residual material leaving the system for the landfill is only 5% to 30% of that of the raw waste It is apparent that the volume reduction of the raw waste by combustion represents a proportional reduction in the area required as landfill and because of its sterility creates fewer environmental problems

3.7.7.2 Energy Production

At present, the sum of all MSW recovery projects corresponds to a rather modest amount of power generation capacity (less than 0 4% of fossil fuel requirements of electric utilities by 1980)

By comparison, if all of the MSW available were to be utilized, it could supply approximately 6%-7% of these fuel needs (data estimated for 1980) Thus, there is ample incentive for expansion and improvemRnt in the field of waste disposal/energy recovery systems

3.8 Heating and Cooling

The earlier systems of heating and cooling originated with forced warm air heating and ventilating systems which incorporated cooling and dehumidification. They had centrally located equipment and distributed tempered air through ducts Complications appeared when heat gain varied within the space served The essential elements and optional components of an air conditioning system are basically categorized according to the means by which the controllable cooling is accomplished in the conditioned area. They are further segregated to accomplish specific purposes by special equipment arrangements These systems, as defined by ASHRAE[1] will be discussed as follows all-air, Section 3.8.1; air-water, Section 3.8.2; all-water, Section 3.8.3; multiple unit, Section 3.8.4

3.8.1 All-Air Systems[2]

An all-air system is defined as a central system providing complete sensible and latent cooling capacity in the cold air supplied by the system Figure 3.8.1-1. No additional cooling is required at the zone (with separate thermostatic control) However, heating may be accomplished by:

—the same air stream either in the central system or at a particular zone

—a separate air stream, water, steam or electric heating system

The important considerations for the energy efficiency of a particular system, of course, are the ability to maintain conditions in no-load zones economically during peak and off-peak loads All-air systems

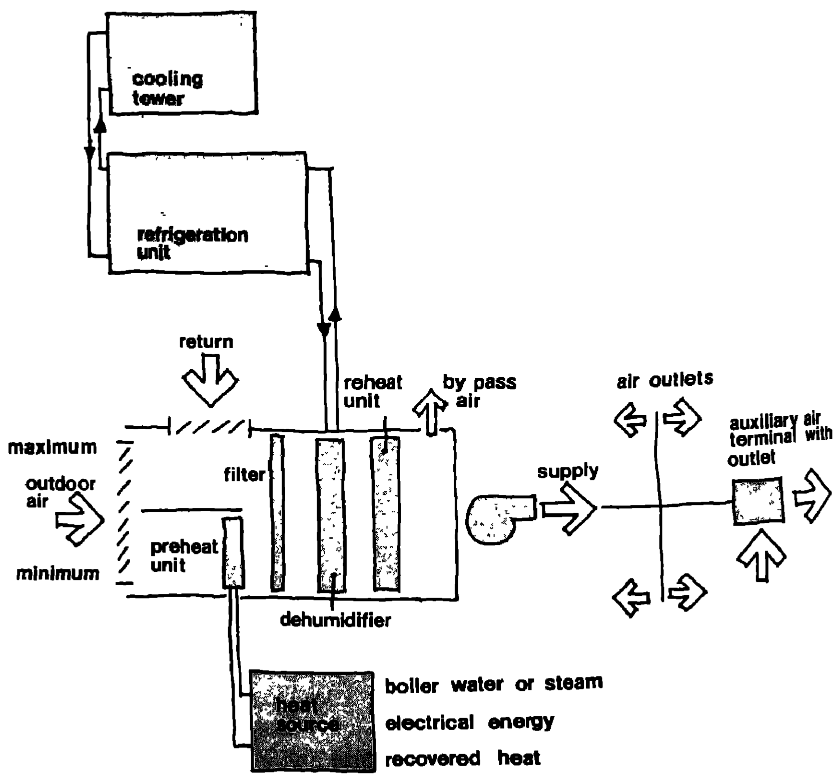


Figure 3.8.1-1
Air conditioning plant, system components.

are applied in buildings requiring individual control of conditions and having a single zone or a multiplicity of zones such as office buildings, schools and universities, laboratories, hospitals, stores, hotels, clean rooms, computer rooms etc

3.8.1.1 Single Duct, Single Zone Systems[3]

The simplest form of an all-air system is a single conditioner serving a single temperature control zone. The unit may be installed within or remote from the space it serves and may operate either with or without distributing ductwork. A rooftop unit, for example, complete with refrigeration system, serving an individual space would be considered a single-zone system However, a single-duct, single-zone type basic central system will have the equipment located away from the conditioned area it serves It may consist of just a single supply system with air intake filters, supply fan and cooling coil, or may be more complex with the addition of a return air duct, return air fan heating coil and various controls to optimize their performance

It is most important that the heat gains and losses within the area conditioned by a central system be uniformly distributed, if a single-zone duct system is to be used Basically, the system supplies air at a pre-determined temperature to one zone or the entire building. The quantity of cooling or heating is controlled either by modulating the supply air temperature or by turning the system on and off A schematic of a single-zone central unit is shown in Figure 3.8.1.1-1.

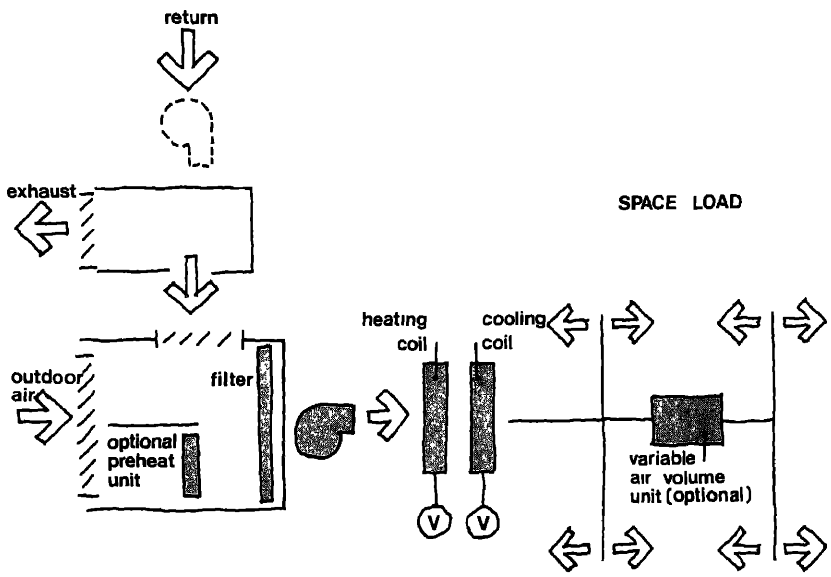


Figure 3 8 1 1-1
Single duct single zone system

Applications and Energy Considerations: A single-zone system may be applied to: small department stores, small individual shops in a shopping centre; individual classrooms of a small school, computer rooms etc. The energy output of the system is determined by the volume/temperature differential relationship. The economizer cycle can be added by an arrangement of damper controls based on

enthalpy of outdoor air, return air and the supply air. Fan volume should preferably be controlled according to demand Energy can be conserved by keeping the supply air volume at a minimum

3.8.1.2 Terminal Reheat Systems[4]

The reheat system is a modification of the single duct/single zone system in order to overcome the zoning deficiencies It achieves this by adding individual heating coils in each branch duct to zones to compensate for areas of unequal loadings, by providing heating of perimeter areas with different exposures, or by providing closer control of relative humidity where this is desired The heat is applied to either preconditioned primary air or recirculated room air A single low pressure reheat system is produced when a heating coil is inserted into the duct system downstream of the cooling coil(s) The more sophisticated systems utilize higher pressure duct designs in order to save space and pressure reduction devices permit system balancing at the reheat zone The medium of heating may be hot water, steam or electricity Terminal units are designed to permit heating of primary air, or secondary air induced from the conditioned space, located either under the window or in the duct system overhead

Applications and Energy Considerations: Terminal reheat allows each different zone to be individually controlled but wastes energy It entails the cooling of all of the supply air to a low enough temperature to meet the most critical load zone but some of this must then be reheated for zones of lesser loads to avoid overcooling Where constant volume is maintained the waste of energy is considerable and for this reason the use of this system should be avoided Ref. Table 3.8.8-T1. A schematic of a terminal reheat system is shown in Figure 3.8.1.2-1.

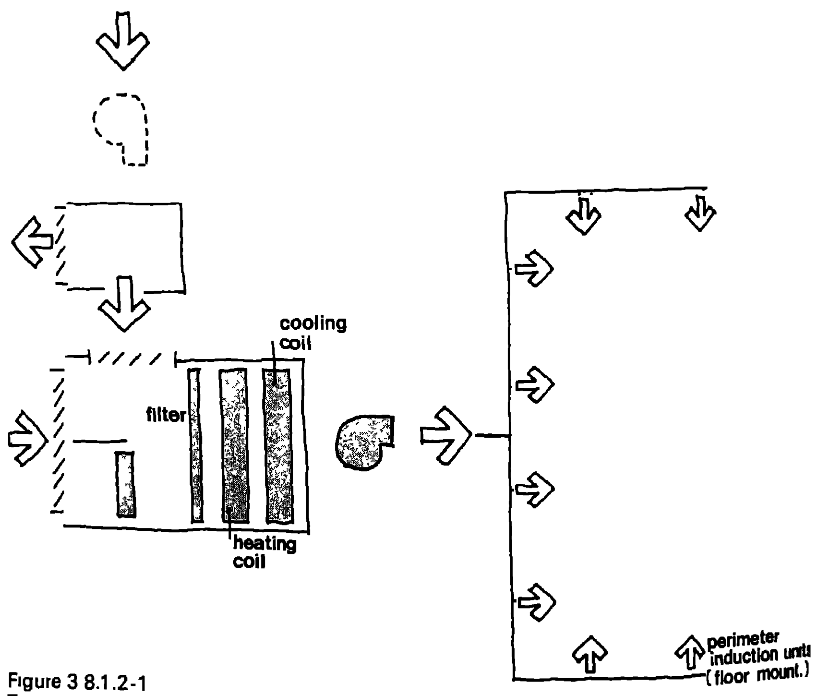


Figure 3 8.1.2-1
Terminal reheat system.

In order to conserve energy with the terminal reheat system some important steps to be taken are as follows:

—Reschedule the supply air temperature control upwards according to demands of the zone with the greatest cooling load and the controlling thermostat should be located in that space.

—Modify controls to operate on a temperature demand cycle only.

The combination of interior terminal reheat with perimeter induction or fan-coil units system, as illustrated in **Figure 3.8.1.2-2** is widely used, particularly in cooler areas. The energy wastage at the perimeter areas is greatly reduced. Only a small portion of the air supplied to perimeter spaces is centrally cooled in the summer and heated in the winter. The remaining perimeter supply air is recirculated within each perimeter space by either induction or fan-coil units.

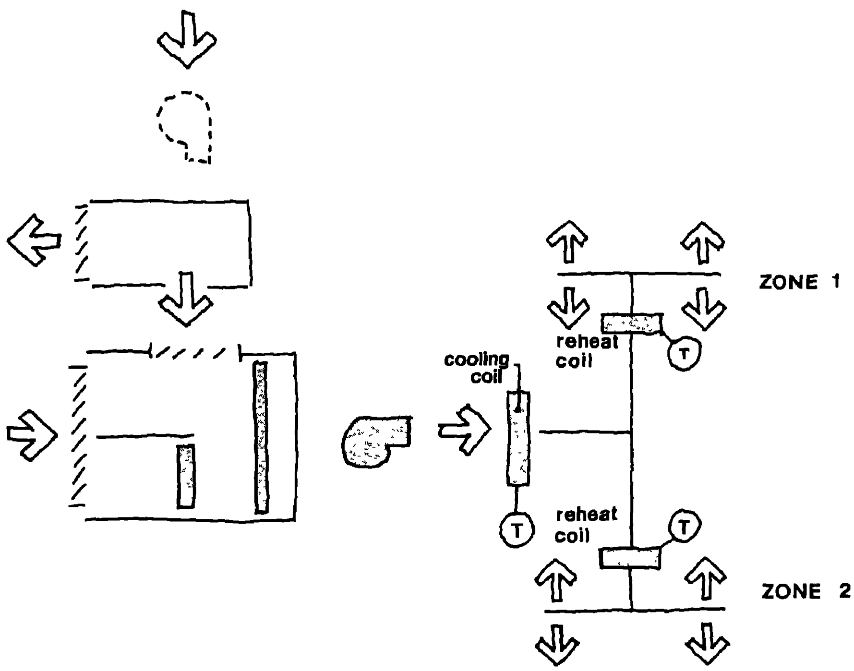


Figure 3 8 1 2-2
Constant volume reheat system with perimeter induction units

3.8.1.3 Constant Volume Induction Systems[5]

The induction system utilizes a terminal unit for reduction of cooling capacity as follows:

—by simultaneous reduction of primary air and increase of induced room air at constant room supply air volume

—by reduction of room supply air

—by terminal reheat when necessary.

The terminal device is employed either in the ceiling cavity above the conditioned space or more frequently, it is located within the room. Generally, it is best applied to systems using a return air ceiling plenum which permits the recovery of available internal heat and also heat from lights which is drawn up through the fixtures.

The terminal units (as illustrated in the **Figure 3.8.1.3-1**) induce varying amounts of high temperature return air in the ceiling space to mix with constant temperature primary air for temperature control.

The primary air is supplied at high pressure, heated if required, to the induction units, discharged from nozzles arranged to induce room air into the induction unit and then heated again if required by a secondary water coil.

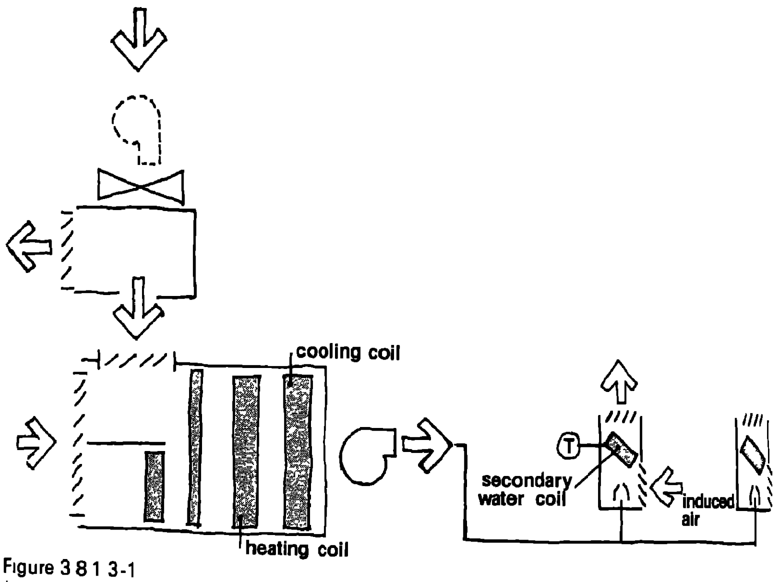


Figure 3 8 1 3-1
Induction system

Applications and Energy Considerations: Energy waste is reduced to some extent with this system since no additional heat is added to the interior spaces under partial loads, and the amount of energy required to reheat at the perimeter spaces is limited to the extent of heating the primary air only In this system some of the internal heat gain can be recovered. The draw-backs are that extensive static pressure control at the terminals is required and extensive ductwork downstream of terminal units poses limitations—since the induction ceases to function where down-stream static pressure exceeds a certain limit Induction unit nozzles may be worn-through easily, resulting in an increased primary air quantity at lower air velocities and lower induced air volumes rendering the system inefficient. Ref. Table 3.8.8-T_1.

Nevertheless, the constant volume induction systems are used for medium and small multi-room buildings, where individual rooms as well as large spaces may be air-conditioned from one central air-conditioning plant They are often applied to buildings having a large ratio of floor area to height, indicating a need for horizontal ductwork and piping These systems have been used for schools, laboratories, hospitals etc where serviceable steam or hot water system is available.

3.8.1.4 Constant Volume Multi-zone[6]

The Multi-zone is a constant volume, temperature controlled system with heating and cooling coils in parallel. It is a central air handling unit system, as shown in Figure 3.8.1.4-1, and serves areas of multiple spaces or zones which require individual temperature control. The requirements of different zones are met by mixing cold and warm air through zone dampers at the central air handler in

response to zone thermostats. The mixed conditioned air is distributed throughout the building by a system of individual zone duct-work. Either packaged factory-assembled units complete with all components or field-fabricated apparatus casings may be used.

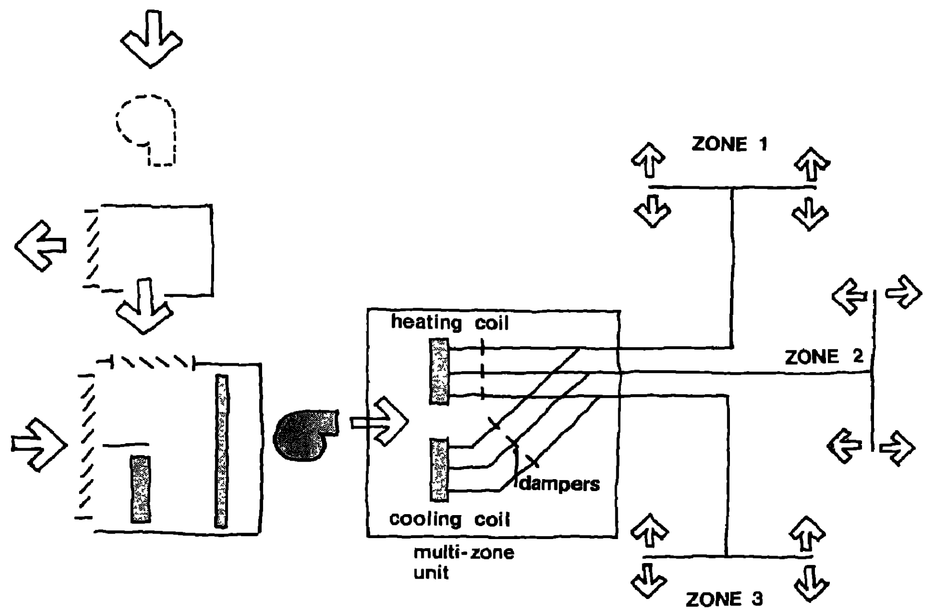


Figure 3.8 1.4-1
Multi-zone system

However, a majority of the applications use one or more factory-assembled units, each of which consists of a mixing chamber, filter, fan, a chamber containing cooling and heating coils, warm and cold air plenums, and a set of mixing dampers to blend the required amounts of warm and cold air to be transmitted through a single duct to outlets in its respective zone. The return air is usually handled in a conventional manner. Additional system components such as a preheat coil, dehumidifying coil, exhaust air fan etc may be incorporated

Applications and Energy Considerations: With this type of unit, the hot deck temperature must be sufficiently high to meet the heating demands of the coldest zones, and cold deck air must be sufficiently low to meet the demands of the hottest zone. All the intermediate zones are supplied with a mixture of cold and hot air, wasting energy in a similar manner to the reheat system. New model multi-zone units are now available on the market which have individual heating and cooling coils for each zone supply duct and the supply air is heated or cooled only to that degree required to meet the zone load.

These new types of unit use far less energy than units with common coils They find applications in areas consisting of several large or small spaces to be individually controlled, a large interior zone with a relatively small group of exterior spaces, such as: a school, a suite of offices, a bank floor of a building, a large open multi-exposure office space, radio and television studios with individual load characteristics within the interior spaces.

3.8.1.5 Dual Duct[7]

This system, as shown in Figure 3.8.1.5-1 conditions all the air in a central apparatus and distributes to the conditioned spaces through two parallel mains or ducts Standard methods of refrigeration and sources of heating are employed to provide the cooling and heating required to the conditioned space One duct carries cold air and the other warm air, thus providing air sources for both heating and cooling at all times

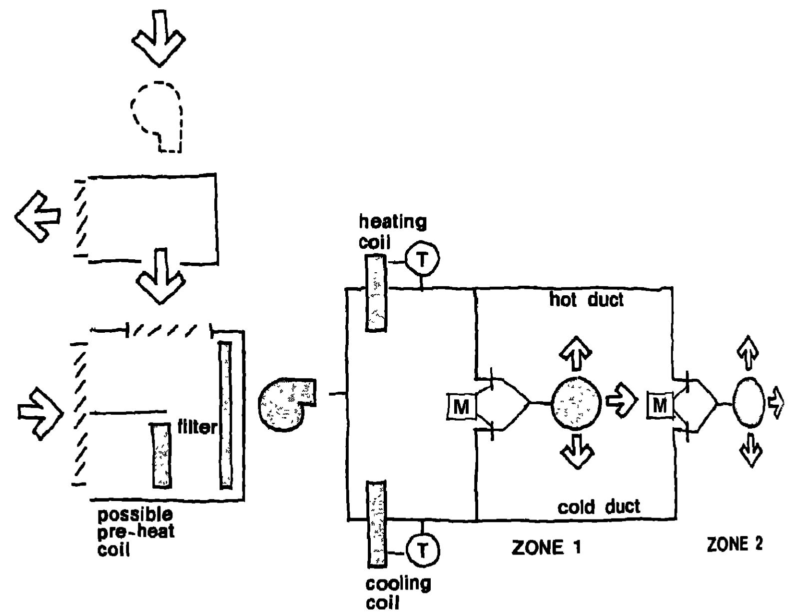


Figure 3 8 1 5-1
Dual duct, low velocity system

In each conditioned space or zone, an automatic damper responsive to room thermostat mixes the warm and cold air in proper proportions in a terminal unit in the branch ducts to satisfy the prevailing heat load of the space In central station apparatus, however, pre-cooling and pre-heating coils can be added to the incoming outdoor air followed by a dehumidifier Instead of one fan handling all the incoming outdoor air, two supply fans may be used one each for the hot and cold air ducts, as shown in Figure 3.8.1.5-2 and each handling a proportion of the total system air delivery The two-fan system is economical to operate and will permit close control of room humidities in summer when less than half of the total air is handled by the warm duct.

Applications and Energy Considerations: The dual-duct system finds its application in a building requiring a multiplicity of zones, such as office buildings, hotels, apartment houses, schools etc

The common characteristic of these multi-room buildings is their highly variable sensible heat load and a properly designed dual duct system may conserve some energy. Attempts should be made to reduce the temperature of the hot duct and increase the temperature of the cold duct to that point where the heating and cooling loads of the most critical zone can just be met. Return air is a mixture of all zones and reflects the average building temperature.

In some designs of central station equipment, it is possible to stratify the return air and the outdoor air by installing splitters so that

the hottest air favours the hot deck and the coldest air favours the cold deck. This will reduce both heating and cooling loads. Energy is wasted when the heating coil is activated to meet only the perimeter heating load or dehumidification. Wastage occurs also during partial load condition when cooled and heated air are mixed to maintain certain temperature

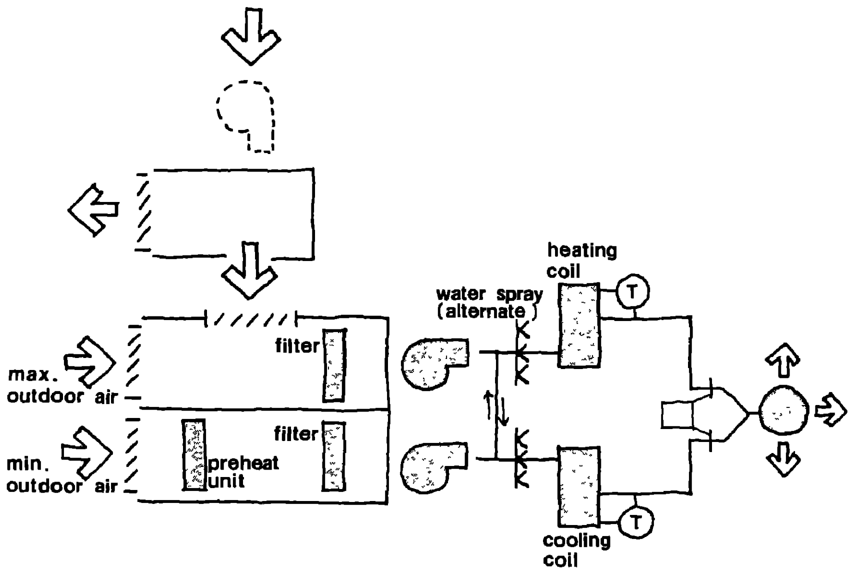


Figure 3 8 1 5-2
Two fan dual duct system, blow-through dehumidifier

3.8.1.6
Variable Volume Air (VAV) Systems[8]

Variable volume, constant temperature systems respond to different conditions and loads prevailing in multiple zones by supplying through a single duct varying quantities of constant temperature conditioned air This air volume is modulated by means of outlet dampers which vary the total supply fan volume in response to demand Both system and zone air volumes may also be varied The zone air volume may be varied by means of a flow control valve or by means of a 'dumping box', which allows excess air to be dumped into a return air ceiling plenum or directly into the return air duct system

A typical VAV system is shown in Figure 3.8.1.6-1. The space temperature control is not dependent on mixing or reheat, thereby eliminating energy waste Simple VAV systems are used for either cooling only or heating only where there is no requirement for simultaneous heating and cooling in various zones. However, in such circumstances heating may be supplied by some form of supplementary system while cooling is achieved by VAV system

VAV systems may be applied to interior or perimeter zones, with common or separate fan systems, common or separate air temperature controls, and with or without auxiliary heating devices VAV systems may also apply to volume variation in the main system total air stream or to the zones of control or both. There are many combinations of design concept, as discussed below

.1 **VAV Reheat or VAV Dual Duct**: In order to achieve energy conservation combined with full heating and cooling flexibility to the interior and perimeter, the system and zone air volumes are varied and

throttled to a predetermined ratio, followed by reheat or warm air mixing at the individual zones. A common fan system can serve interior and perimeter with or without variable volume in the interior and with reheat for duct branches serving individual exposures, then handling each zone in an exposure with variable volume.

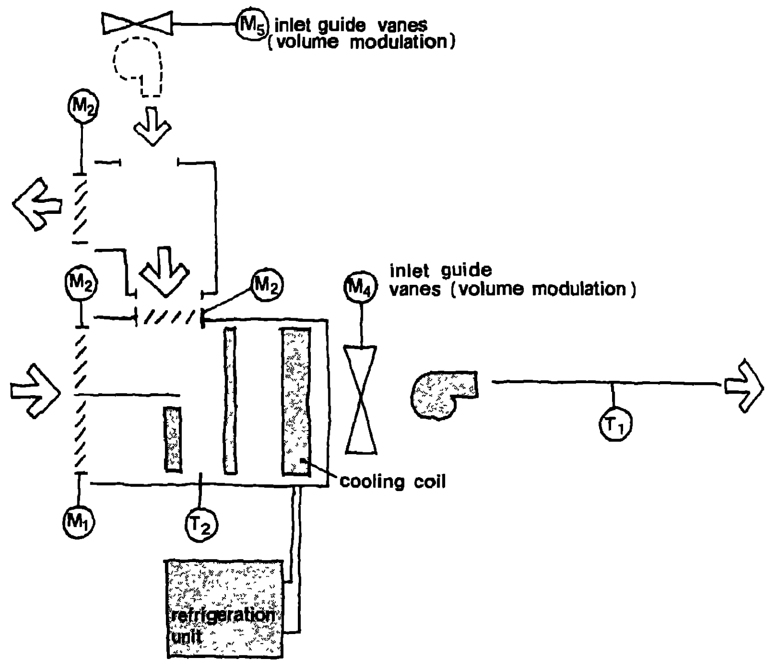


Figure 3.8.1.6-1
Variable volume (VAV) constant temperature system

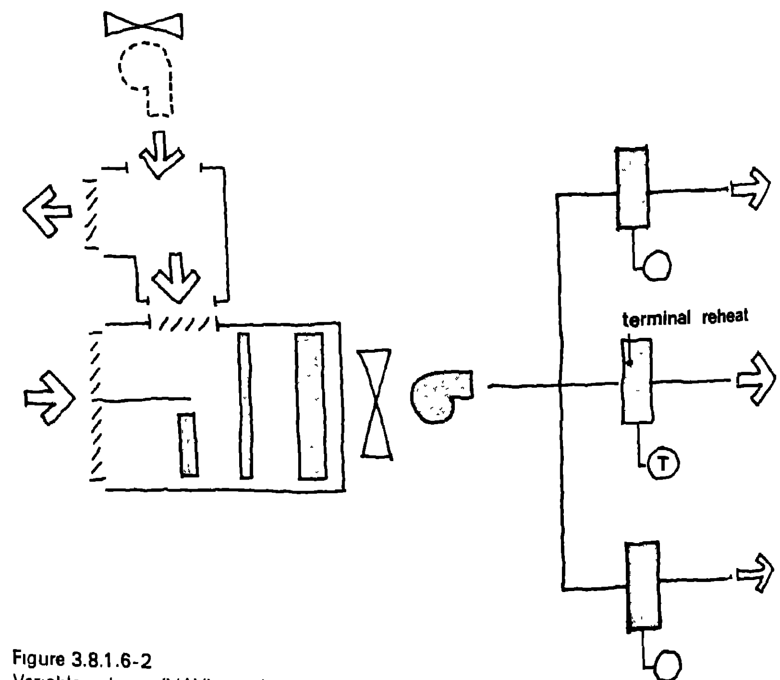


Figure 3.8.1.6-2
Variable volume (VAV) terminal reheat system

The VAV terminal reheat system is illustrated in Figure 3.8.1.6-2. With decreasing cooling load in a space, the air volume decreases without activating the reheat coil. However, when the air volume reaches a preset minimum, the reheat coil is activated. Terminals without reheat coils can be used in interior spaces. Energy waste is reduced since the supply air to be heated is limited to the perimeter units only, and moreover, the air volume is reduced to a minimum before heating is activated

The VAV dual duct system is illustrated in the Figure 3.8.1.6-3. With a reduced space cooling load, the cold air volume decreases in the terminal without opening the hot air damper. Only when the cold air volume decreases beyond a pre-set minimum does the hot air damper commence a mixing action. Interior spaces can, generally, be served with a single cold duct and variable volume terminals, when there is no requirement for a minimum ventilation rate Energy waste is reduced since the amounts of hot and cold air to be mixed are kept to a minimum.

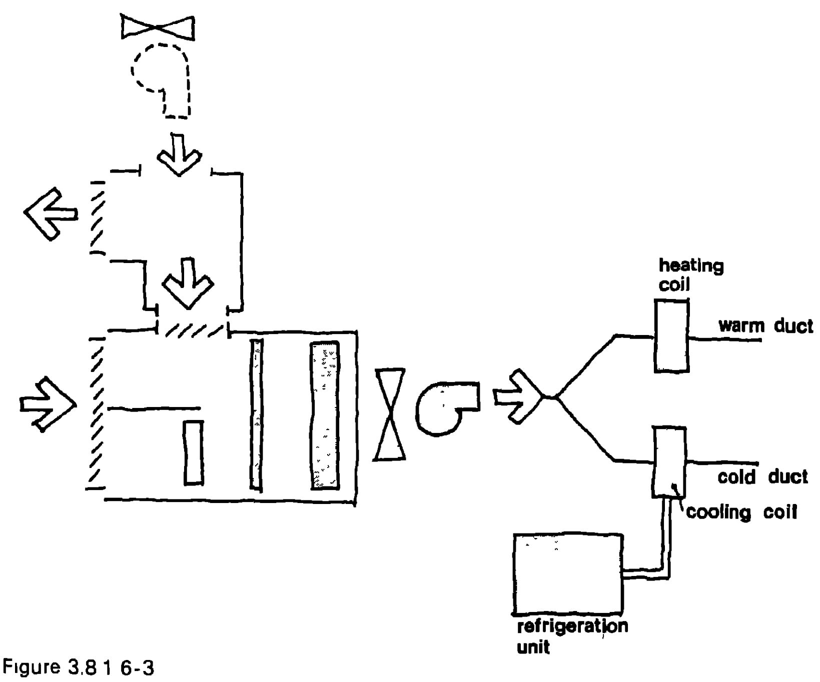


Figure 3.8 1 6-3
Variable volume (VAV) dual duct system

.2 VAV Independent Perimeter System (Air or Hydronic): This system comprises a simple variable volume system for the interior of the building with a constant volume perimeter air system which accomplishes all cooling and heating with air. The variable volume system, on an all-season cooling cycle, takes care of all variations in all zone internal heat gains as well as skin solar gains The perimeter system uses an outdoor/indoor temperature-scheduled constant volume air supply whose function is simply to offset the skin transmission gains or losses The perimeter system requires no individual zone control (except for operating economy) and no outdoor air since the variable volume system takes care of each zone's load variations (except transmission) and it may contain the total outdoor air ventilation supply for all zones.

The simple variable volume system with an independent hydronic perimeter heating system accomplishes all cooling in all zones with air, on an all-season cooling cycle, while the perimeter heating system offsets the transmission heat losses (but not the summer transmission heat gains). Radiation which is customarily specified need not have individual room control of an automatic or manual nature, but it sometimes does have this for better manual or automatic flexibility and operating economy

.3 **VAV Perimeter Constant Volume (or dual conduit system):** This system is designed to supply two air streams to exposures that have a reversing transmission load It consists of an all air perimeter system with a constant volume, variable temperature air stream, equipped with both cooling and heating coils to neutralize the transmission loads in the heating and cooling season To minimize energy use, 100% recirculated air is used in the perimeter system Outside air required for ventilation enters the conditioned spaces through the variable volume, interior, constant temperature, system to match the general loading capacity In the exterior spaces, constant volume perimeter air is introduced into the space either by using a series of perimeter slot diffusers, or by connection to the variable volume system which discharges into the space through common diffusers.

.4 **Pulsating Zone VAV with Constant System Volume:** This technique involves an intermittent pulsating supply to each zone, its length and frequency of supply being timed to balance the zone load, while the excess is dumped into the ceiling or return air system It may or may not be combined with terminal reheat

Applications and Energy Considerations: Specific energy conservation and cost saving features of VAV systems with their various combinations are as follows.

—Full advantage may be taken of shifting loads from lights, occupancy, solar, equipment etc., permitting diversities and simultaneous heating-cooling flexibility

—Operating energy cost savings will result from
  - fan energy savings from long-hour usage at reduced volumes and from installed fan kW reductions
  - savings on refrigeration, heating and pumping energy
  - improved free-cooling economy
  - full cutoff of unoccupied areas
  - internal source of heat recovery systems (internal heat is not diluted with an unnecessary amount of primary air)

—There will be a lower total cost for fans, refrigeration, heating and associated plant auxiliaries

VAV system combinations are well suited for most applications such as office buildings, department stores, hotels, hospitals, apartment houses, schools and elsewhere.

3.8.2 Air-Water Systems[9]

An air and water system is one in which both media are distributed to each space in order to perform the cooling and heating function Most applications utilize the two distribution systems to provide the simultaneous availability of both cooling and heating. In virtually all air-water systems, both cooling and heating functions are carried out

by changing the air or water temperatures (or both) to permit control of space temperature during all seasons of the year.

The quantity of air supplied can be low compared to an all-air system and a substantial part of the heat gain can be removed directly from the conditioned space by a recirculating water system If the system is designed so that the air supply is equal to the air for ventilation or to balance exhaust requirements or both, the return air system can be eliminated for the areas conditioned in this manner

Applications and Energy Considerations: The pumping necessary to circulate the water throughout the building is usually significantly less than the fan-power required to deliver and return the supplanted air The fan operating cost savings can be quite substantial when compared with all-air, constant-volume, medium or high pressure systems

The water side, by complementing rather than totally replacing the air side, retains for air-water systems many of the major performance capabilities of more versatile all-air systems. These include positive ventilation, central dehumidification and winter humidification as well as good temperature control over widely fluctuating sensible cooling and heating load conditions for a large number of control zones.

Air and water systems are primarily applicable to multiple perimeter spaces where a wide range of sensible load exists and where close control of humidity is not required Systems of this type have been commonly applied to office buildings, hospitals, hotels, schools, better apartment houses, research laboratories, and other buildings where system capabilities can be properly utilized to satisfy performance criteria Their space-saving characteristic has made these systems especially beneficial for use in high-rise structures.

Air and water systems are categorized as two-pipe, three-pipe, and four-pipe systems. They are basically similar in function and all incorporate both cooling and heating capabilities for all-season air conditioning However, as discussed later, arrangements of the secondary water circuits and control systems differ greatly.

3.8.2.1 Two-Pipe Systems

Two-pipe systems derive their name from the water distribution system, which consists of one supply pipe and one return pipe Each unit or conditioned space is supplied with secondary water from this distribution system, and also with conditioned primary air from a central apparatus The heating or cooling capacity of any given unit at a particular time is the arithmetic sum of the primary air output plus the secondary water output of that unit

The secondary water coil output of each terminal is controlled by a local space thermostat, and can vary from zero to 100% of coil capacity as required to maintain space temperature. The secondary water is cold in summer and intermediate season, and warm in winter. All rooms on the same secondary water zone must operate satisfactorily with the same water temperature.

3.8.2.2 Three-Pipe Systems

Three-pipe systems utilize three water pipes to each terminal unit: a cold water supply, a warm water supply, and a common return.

Three-pipe systems have been classified into two categories, terminal mix and return mix systems.

In both types of systems, hot and cold secondary water are provided at the units and, depending on the type of system, either are mixed before entering the unit or are utilized in the unit selectively in accordance with temperature requirements. Both systems use a common return pipe

The three-pipe system satisfies variations in load by providing independent sources of heating and cooling to the room unit in the form of constant temperature primary and secondary chilled and hot water Any unit in the system can be operated through its full range of capacity (offering greater heating/cooling flexibility) without regard to operation of any other unit in the system It should be recognized that there will be an operating cost penalty if heating and cooling loads are satisfied simultaneously

3.8.2.3 Four-Pipe Systems

Four-pipe systems derive their name from the four pipes to each terminal unit: chilled water supply; chilled water return, warm water supply, and warm water return The four-pipe system satisfies variation in cooling and heating load by providing independent sources of heating and cooling to the room unit in the form of constant temperature primary air, secondary chilled water, and secondary hot water, Figures 3.8.2.3-1, 2.

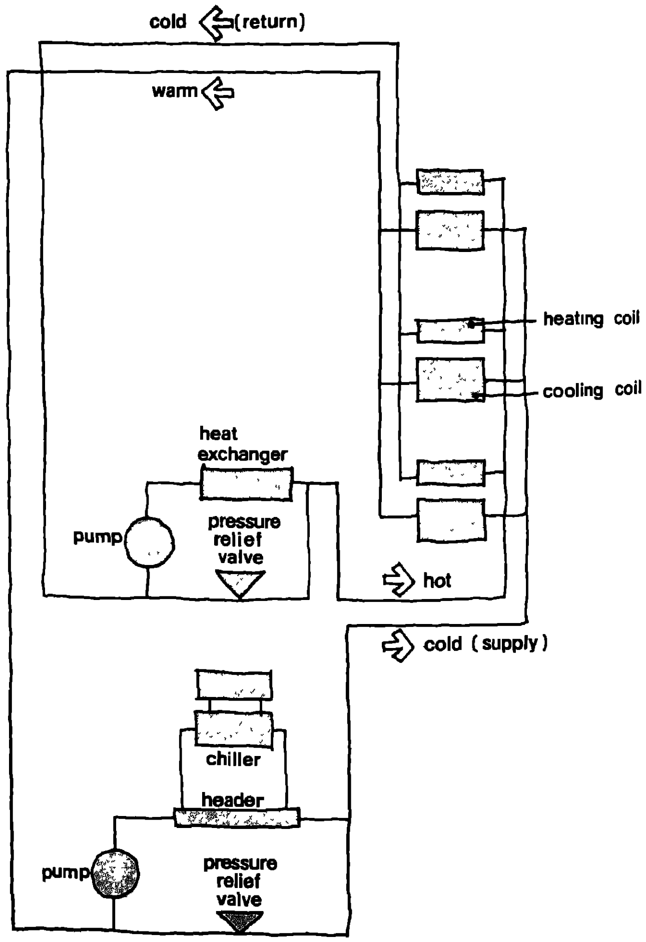


Figure 3.8.2 3-1
Four-pipe system, two coils

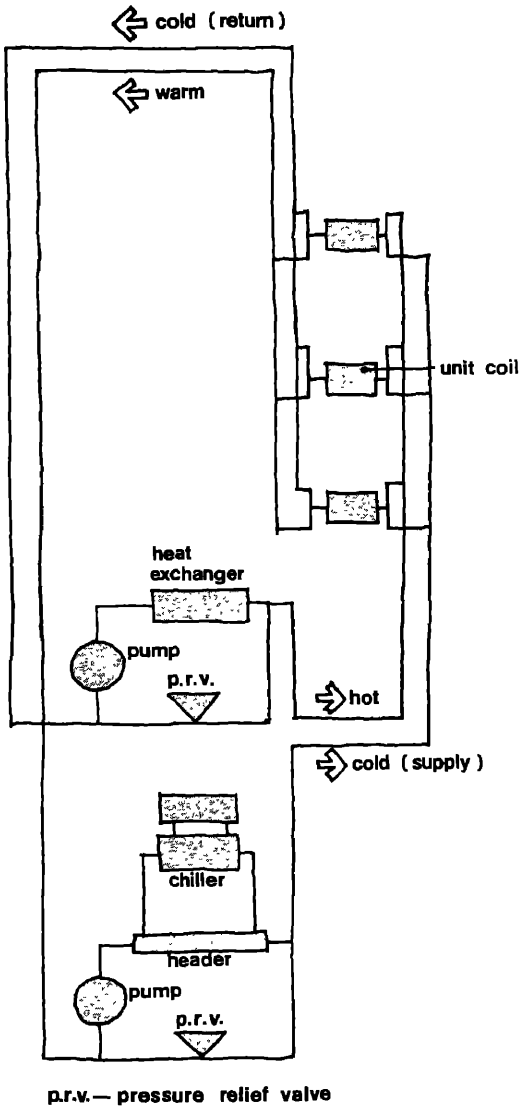


Figure 3.8 2 3-2
Four-pipe system, reverse flow through coil

During the period between seasons, any unit can be operated at any capacity level from maximum cooling to maximum heating, if both chilled water and warm water are being circulated Any unit can be operated at or between these extremes without regard to the operation of any other unit.

Since the primary air is supplied at a constant cool temperature at all times, it is sometimes feasible to extend the interior system supply to the perimeter spaces eliminating the need for a separate primary air system. The type of terminal unit and the characteristics of the interior system will be determining factors This technique is applicable to both three-and four-pipe systems.

3.8.2.4 Air-Water Induction Systems

In an air-water induction unit centrally conditioned primary air is supplied to the unit plenum at high pressure.

The high pressure air flows through the induction nozzles and induces secondary air from the room and over the secondary coil This secondary air is either heated or cooled at the coil depending on the season, the room requirement, or both. The primary and secondary air is mixed and discharged to the room.

Induction units are installed in custom enclosures designed for the particular installation, or in standard cabinets provided by the unit manufacturer. Induction units are usually installed at a perimeter wal under a window, but units designed for overhead installation are available.

A wide variety of induction unit configurations is available, including units with low overall height or with extremely large secondary coil face areas, to suit the particular needs of space or load.

Primary Air System: In a primary air system the components are completely conventional for a high pressure design, but there are some which relate to induction systems and deserve mention Primary air systems usually are designed to operate with 100% outdoor air

Air-water systems employing induction units have the following characteristics·

—Located under the window, the induction unit can operate as a convector during off hours It is not usually necessary to operate the air system to obtain off-hour heating.

—Under-window induction units effectively distribute air for heating and cooling.

3.8.2.5 Dual-Duct Induction System

This system is a hybrid, consisting essentially of a dual-duct system with mixing boxes designed to accommodate the full heating and part of the cooling load. The mixing boxes contain induction nozzles and a secondary room coil which receives cooled secondary water to extend the unit capacity during the summer

The secondary water system may be shut down during the off seasons, and the system could then operate as a dual-duct system

Induction Unit: A dual-duct induction unit includes primary cold and hot air connections, a mixing valve, a constant volume regulator, and a secondary coil The presence of the regulator permits (1) the installation of the system with the air balance set in the factory, and (2) the combining of the ductwork serving the perimeter portions of the building with a conventional dual-duct air handling system

Primary Air: The equipment is conventional for a high pressure dual-duct system. Primary air is not zoned.

Secondary Water: The secondary water systems are similar to those illustrated for two-pipe induction systems.

Applications and Energy Considerations: This combination of air induction air-water and dual-duct systems offers a method of providing individual space control of both cooling and heating capacity throughout the entire year. In this regard, it shares the advantages of three and four-pipe air-water systems over the two-pipe version, in which heating of the primary air during the summer cycle must be scheduled to prevent overcooling of the lightly loaded spaces, while elsewhere the cool secondary water must offset at least partially this heating capability. The dual-duct induction, in effect, substitutes the hot air duct for the hot water

supply system of three and four-pipe systems. A comparative evaluation with these systems should consider space requirements (particularly of the distribution systems and unit enclosure), and ventilation requirements (a high requirement could favour this concept, such as might occur in laboratories with heavy exhaust rates)

Simplification of the air handling unit and duct layout may be possible if all-air dual-duct distribution is to be used for interior space In such cases, interior and perimeter systems may share a common air supply, without incurring the high air quantities required to meet the solar loads of the perimeter spaces such as would be necessary in a completely dual-duct approach. The ability to heat by convection at night avoids the necessity of the off-hour fan operation required of an all-air perimeter system

3.8.2.6
Fan-Coil Conditioner System with Primary Air

The fan-coil conditioner unit is a versatile room terminal which is applied to both air-water and water-only systems. Despite the shortcomings in the quality of air conditioning achieved with water-only systems, the fan-coil units have been more commonly associated with that class of system than with air-water Many of the standard features of the units are accordingly incorporated into it for water-only applications.

The basic elements of fan-coil units are a finned-tube coil and a fan section The fan section recirculates air continuously from within the perimeter space through the coil which is suppled with either hot or chilled water. In addition, the unit may contain an auxiliary heating coil which is usually of the electric resistance, steam or hot water type Thus, the recirculated room air is either heated or cooled.

Room fan-coil units are available in a number of physical configurations, such as vertical wall-mounted units and a horizontal ceiling-mounted models Low vertical units are available for use under windows with low sills, however, in some cases the low silhouette is achieved at a compromise of such features as filter area, motor serviceability, and cabinet style

In northern climates where heat is needed along the exterior wall, the vertical models are generally applied under (or adjacent to) a window It is necessary to blanket the window area with the warm air discharge from the fan-coil unit To accomplish this, manufacturers offer several different types of fixed vane and adjustable vane discharge grilles In southern climates where heat is not needed along the exterior wall, the horizontal models are frequently used.

Primary Air System: The primary air system for an air-water fan-coil system differs from that of an induction system primarily in that the air supply need not be integrated (and usually is not) with the water-side terminal

If vertical fan-coil units are to be installed beneath the windows at the outside wall, it is not uncommon to supply the primary air from overhead either from a sidewall register at the corridor wall or from ceiling diffusers.

Applications and Energy Considerations: There may be a temptation to apply fan-coil terminals, with two-pipe distribution, in combination with a constant temperature interior air distribution network extended to the perimeter spaces of office buildings. While this concept does offer an improved source of ventilation air and

humidity control over water-only systems, the temperature control during the intermediate seasons will be inferior unless the water system is zoned according to solar exposure.

Air-water systems employing fan-coil units have the following characteristics:
—Building management can reduce operating costs during partial occupancy by shutting unit fans off in unoccupied areas.
—Under-window fan-coil units effectively distribute air for heating and cooling.
—Units can provide only limited heating capacity as convectors during unoccupied hours.

3.8.3 All-Water Systems[10]

All water systems are those with fan coil or unit ventilator with unconditioned ventilation air supplied by an opening through the wall or by infiltration Cooling and dehumidification is provided by circulating chilled water or brine through a finned coil in the unit Heating is provided by supplying hot water through the same or a separate coil, using two, three, or four-pipe water distribution from central equipment. Electric heating or a separate steam coil may also be used

Applications and Energy Considerations: This system is flexible for adaptation to multi-room building requirements such as hotels, motels apartments and small office buildings without the need of complicated ductwork. When used with any central station perimeter system utilizing water in pipes instead of air ducts, considerable space and installation cost savings may be achieved Energy savings may be achieved by using the interior zone load as heat source Major drawbacks of this system are as follows
—positive ventilation, quantity of outdoor air and humidity control limited to the effect of exhaust from room and the size of the wall openings, outside wind pressure and stack action on building
—special precautions required at each unit with outside air opening
—unsatisfactory appearance of the building due to wall openings
—energy waste during intermediate seasons and differences in zonal loads

3.8.3.1 Fan-Coil Units

All-water fan-coil units are used with two, three or four-pipe water distribution systems A supply of hot and cold water is available at each fan coil unit. The fan-coil unit construction is described in detail in the previous Section 3.8.2.6. Vertical models are usually installed along an outside wall with provision for introducing varying degrees of ventilation air from outside. Horizontal models for ceiling applications are also available without provisions for positive ventilation or with a separate ventilation air duct system

3.8.4 Multiple Units or Unitary Systems[11]

Multiple units are used for unitary zoned systems, with each zone served by its own unit. The room conditioner carries this concept to relatively small rooms. For large single spaces, where central systems are at their best advantage, application of multiple units often finds advantage due to movement of load sources within the larger space.

giving the flexibility of many smaller interlocked and independent systems instead of one large central system.

Applications and Energy Considerations: For small rooms or spaces multiple unit systems provide·
—simple, inexpensive and individual control, often manually achieved by the occupant himself
—individual air distribution system, heating and cooling capability is provided at all times for each room independent of other spaces
—a completely packaged system with manufacturer's guarantee of operating efficiency
—energy savings due to the total shut down of units of un-occupied and no-load areas without affecting other zones

3.8.4.1 Packaged Terminal Air Conditioners

Each packaged terminal air conditioner has a self-contained direct-expansion cooling system, heating coil (electric, hot water, or steam), and packaged controls The units may have separate heat section and cooling chassis or a combination heating and cooling chassis.

3.8.4.2 Rooftop Systems

A unitary rooftop system utilizes unitary cooling equipment of the direct expansion type in which at least the fan and the evaporator are mounted on the roof. The air distribution ductwork must penetrate the roof. The compressor and condensing section may be mounted remotely, but is more often packaged with the fan and evaporator. The complete system consists of the unitary equipment, air distribution and air delivery system(s), interlocking controls etc

Multiple unit rooftop systems provide an economical first cost method for year-round air conditioning of buildings, particularly one or two-storeys high, with relatively flat roofs, and requiring separate and independent control of relatively small interior spaces. These systems may not be economical for application to buildings whose heat loss is a major consideration.

3.8.4.3 Unitary Air Conditioners and Systems

The unitary air conditioner consists of a direct expansion evaporator or cooling coil, a compressor and condenser combination and may also include a heating function Air cooled condensers are preferred because of elimination of winterizing problems. The systems using unitary air conditioners may range from a series of single rooms (of various sizes and loads), each handled by a single conditioner, to mixtures of single room-single conditioner, multiple room-single conditioner and single room-multiple conditioner situations. All single unitary conditioners may be equipped with factory-built or field-fabricated air plenums for supply air distribution systems. Different variations of this system are available in conjunction with central or terminal reheat, variable air volume, coil by-pass etc

.1 **Single Unit with Reheat:** A small store with outside exposures can be served by this system, maintaining constant air volume with a single unit. However, as common with all reheat systems, the equipment must be oversized to meet the combined maximum loads for all areas cooled and, therefore, energy is wasted to overcool some areas and then reheat them.

.2 **Single Unit with VAV:** As discussed before, VAV offers an excellent means of temperature control with optimum energy savings At no time is air cooled down only to be reheated later or mixed with warm air. The by-pass version of the VAV is the most useful for unitary equipment, because airflow through the conditioner is not reduced Terminals of this type are available which vary quantity by timed pulsations (with all air going either to the conditioned space or to return air)

.3 **Multiple Unit Systems:** Multiple systems with individual controls for areas combined with one separate all-outdoor air unit, can maintain close control in all parts of a large building with outside exposures and high percentage of glass area The units are packaged in a single cabinet Zone control is accomplished by mixing air from the cold and hot deck coils to meet zone requirements, thus allowing some energy savings The outdoor air unit continues to operate in mild weather even if the zone thermostats may have one or more inside units turned off This prevents the introduction of hot, humid air into the conditioned space under periods of light loading

3.8.5 Multi-Energy Equipment for Heating and Cooling

In general, most heating and cooling equipment is designed to draw energy from one of the readily available sources such as oil, natural gas, electricity etc. However, some equipment may also utilize different sources of energy for different functions in order to conserve energy in the overall performance. Sometimes, equipment utilizing different sources of energy may be integrated into one system

3.8.5.1 Reasons for Use

The reasons for utilizing multi-energy equipment or systems may be the relative scarcity and economics of the various forms of energy available in certain areas, under certain circumstances and for certain applications such as:

—where electrical energy is scarce and expensive, large heating load requirements may be economically satisfied by either oil or gas

—in some cases, natural gas may be more economical than oil etc

3.8.5.2 Examples

Some examples of multi-energy equipment and systems will be discussed briefly

—Packaged air conditioners are designed for electrical direct expansion cooling and gas-fired or oil-fired heating. This equipment may be used as a single unit, as multiple units or as rooftop systems. The same unitary packaged systems may also be combined with electrical reheat or hydronic perimeter units

—Furnaces designed to burn natural gas which can also be changed over to burn oil, depending on the availability and the economic considerations of fuel in an industrial or commercial environment These forced air heating systems may utilize terminal reheat with electric coils where areas of different ambient conditions may be served by a single system.

—Furnaces for residential use designed to burn wood or oil The oil supply cuts in when the wood feed is expended, for instance when the house is left unoccupied.

—In industrial buildings, electric space heating for office comfort may be supplemented by the gas-fired make-up air requirements.
—In total energy systems used in industrial buildings, heating may be achieved by equipment recovering waste heat from prime movers burning gas and/or oil.
—In large buildings, wasted heat from different energy sources (e.g. electric lighting, gas or oil fired boilers, refrigeration equipment, exhaust air, hot water systems etc) may be recovered through heat pumps for proper utilization.
—Where a solar energy system is used for heating, electric or oil fired back-up systems can be incorporated to form a multi-energy system. Integrated systems utilizing solar and another renewable energy source, such as wood, are also possible Both sources could also supply heat to a common heat storage bin or reservoir.

3.8.6 Electric Heating and Other Heating Systems[12]

Electricity is energy in a refined form, simple to distribute and control It is still being widely used for space heating in residences, schools, office buildings, and in many commercial and industrial establishments. However, electric space heating has been used for too many applications where minimum initial cost was the dominating factor.

Electricity, being an expensive and likely scarce commodity, should not be used for base comfort heating as it is the most wasteful use of this form of energy. It could instead be used to supplement other types of heating systems—such as solar. It is far more sensible, in the case of fossil fuels, to burn them at the end users' premises than in central electric power generating stations where a substantial proportion of the energy input is expended in generation, transformation, transportation etc before it can be used in the form of electrical power

3.8.6.1 Electric Heating

An electric heating unit is a frame, casing, or other supporting means containing one or more heating elements, electric terminal connections or leads, and electrical wiring and insulation, all assembled into a unit which is CSA approved.

.1 **Electric Resistance Heating Elements:** Electric resistance heating elements usually are composed of metal-alloy wire or ribbons, non-metallic carbon compounds in rod or other shapes Heating elements may have exposed resistor coils mounted on insulators, metallic resistors embedded within refractory insulation encased in a protective metal sheath. Fins or extended surfaces may be used to add heat-dissipating area.

Coiled resistors in quartz tubes, metal sheath elements, or special incandescent lamps with tungsten filaments and glass or quartz envelopes are designed to produce maximum energy in the infrared portion of the electric magnetic spectrum They are applied as radiant heaters.

.2 **Types of Electric Space-Heating Systems:** Types of electric heating equipment and complete heating systems in current use are listed in **Table 3.8.6-T$_1$**. (See **Section 3.4.1** for more descriptive data.)

3.8 Heating and Cooling

DECENTRALIZED SYSTEMS
Natural Convection Units
(1) Floor drop-in heaters
(2) Wall insert and surface mounted heaters
(3) Baseboard convectors
(4) Hydronic baseboard convectors with immersion elements
Forced Air Units
(1) Unit ventilators
(2) Unit heaters
(3) Wall insert heaters
(4) Baseboard heaters
(5) Floor drop-in heaters
Radiant Units
(1) Radiant-convector panel heaters
(2) Metal-sheathed element with focusing reflector
(3) Quartz tube element with focusing reflector
(4) Quartz lamp with focusing reflector
(5) Heat lamps
(6) Valance heaters
Radiant Panel-Type Systems
(1) Radiant ceiling with embedded conductors
(2) Pre-fabricated panels
(3) Radiant floor with embedded conductors
CENTRALIZED SYSTEMS
Heated Water Systems
(1) Electric boiler
(2) Electric boiler, with hydronic off-peak storage
(3) Heat pumps
(4) Integrated heat recovery systems
Steam Systems
(1) Electric boiler, immersion element or electrode type
Warm Air Systems
(1) Duct heaters
(2) Electric furnaces
(3) Heat pumps
(4) Integrated heat recovery systems
(5) Unit ventilators
(6) Self-contained heating and cooling units

Table 3 8 6-T_1
Electric space-heating systems

.3 Fresh Air Supply and Moisture Control: The use of improved building techniques, additional insulation, vapor barriers, and reduction of infiltration losses to a minimum effectively avoids the waste of energy but may occasionally result in excessive humidity under certain conditions of occupancy

To control excessive humidity during times of high internal moisture generation, an exhaust fan may be used with humidistat control An alternative is to increase the rate of fresh air intake by humidistat control

Continuous powered intake and tempering of fresh air can be provided at an adequate rate Suitable devices are commercially available for use with non-ducted electric heating

.4 Thermostatic Control: In terms of heat output, electric in-space heating systems may be classified as radiant, natural convection, or forced-convection. The operating characteristics of each type must be considered in applying thermostatic controls to achieve acceptable temperature control. Higher mass structures have longer time constants and permit acceptable operation at lower cycling rates. In any heating system with on-off control, the operating differential of the thermostat is a complex factor combining the effects of the cycling

rate of the thermostat, heat anticipation, heater mass, transport time, and mass of the structure and room furnishings and, most important, location of the thermostat.

.5 **Energy Management:** Energy conservation is a prime concern with any system, including electric With electric systems, consideration of peak rate of energy use, and time of day of the peak, becomes almost as important as total energy use, both economically (in most non-residential rate structures) and in terms of impact on energy resources. If the instantaneous environmental system peak rate of energy use (demand) is at the same time of the day as the utility peak demand from all users, all of the environmental system demand contibutes to the utility peak, and requires its share of generating capacity to be provided especially for it If, however, the peak environmental demand can be minimized to 60% of its uncontrolled peak during the utility peak period. only 60% as much generating capacity is required for it, even though the entire environmental systems peak is fully realized outside utility peak periods

Decentralized systems, with separate thermostatic control for each room, tend toward minimizing peak demands well below the total connected load of the heating equipment, if operated without control temperature setback or periodic turn off of equipment resulting in cold-start operation when reset to comfort temperature or turned back on.

When decentralized equipment is combined into a system with manual or automatic temperature setback, peak demands can be reduced by sequentially turning on sections or zones to be brought up to temperature, with at least two electric demand metering time intervals between turn-ons. (If the demand is based on 15 min intervals, at least 30 min between zone turn-ons, if a 30 min demand interval, at least 1 h between turn-ons.)

Further reduction may be accomplished by using a demand limiter, which monitors actual demand and deenergizes selected deferable loads when the demand approaches closely or exceeds a preset target maximum Some control manufacturers are now providing constant monitoring control systems with computerized operation to minimize electrical demand (Refer to **Section 3.4.4.**)

Heat recovery offers opportunity for savings in operating cost and energy resources. Any exhaust air stream or venting of heat producing devices should be examined for heat recovery possibilities.

3.8.6.2 Other Heating Systems

The systems described under this heading are classified according to their heating and cooling mediums, namely, steam water and air

.1 **Steam Heating Systems:** This heating system uses steam to supply heat to a conditioned space or a process, connecting a source of steam, through piping, with suitable terminal heat transfer units located at the space or other heating process in air conditioning units such as fan-coil units, heating coils of an absorption refrigeration machine etc. Modern systems can vary the steam temperature and heating effect over wide ranges to control space temperatures or heating processes. When comfort heating and air conditioning equipment are the main uses of the steam produced, low pressure steam systems are preferred. However, often when used in our industrial environment, high pressure boiler plant may be

essential Both one-pipe and two-pipe systems are used for comfort heating

Applications and Energy Considerations: The flexibility and versatility of control make the steam heating systems readily adaptable to a wide range of system sizes and process applications Steam systems are often preferable to water systems where excessive static water pressure is encountered due to lengthy and complicated piping Energy conservation can be achieved by reducing pumping power compared to water systems

.2 Hot Water Heating Systems: Similar to steam, in a water system hot water is used to convey heat to a conditioned space or process through piping connecting a boiler, water heater etc with suitable terminal heat transfer units located at the space or process In terms of flow generation, there are two types (a) gravity system and (b) forced system using electric motor driven pump

Applications and Energy Considerations: The forced recirculated type hot water systems are used very commonly in residential heating applications. They are, also, being used in many large building heating systems as they provide the following advantages

—an economic means of matching system heat output to load requirements, minimizing overheating and energy waste

—comfort by uniformity in surface temperatures of heating equipment as a result of automatic controls, maintaining water flow rates at varying temperatures

—a simple means of introducing heat with uniform response to load changes, along entire outdoor exposures through the use of baseboard, finned radiation, or radiant ceiling panels

.3 Forced Air Systems: In forced air systems, the hot air circulation is effected by electric motor driven centrifugal fans Air is heated by means of a centrally located furnace and then distributed by means of a network of duct and supply outlets Based on the distribution system and the location of the outlets, the forced air systems may be classified as (a) inside wall systems where the outlets are located on the inside wall near the floor or ceiling, and (b) perimeter systems, in which the conditioned air is introduced upward into the room at or near the floor along the outside walls, preferably under windows The return air is taken back into the furnace through openings in the inside walls or ceiling grilles. The conditions of comfort obtained in a room are largely determined by the type, location and distribution of supply outlets and to a much lesser extent, the location of the return grilles

Applications and Energy Considerations: Forced air systems are equally adaptable for use in residential and non-residential structures Although, most commonly found in one and two family residences, recent developments in equipment and system design have contributed to the increased use of forced air systems in school buildings, apartment houses, and commercial and industrial structures Other factors which have contributed to this trend include the desire to use one distribution system for both winter and summer air conditioning, and the desire of owners to turn over to the tenant responsibility for all utilities in apartments and commercial buildings Some of the advantages are as follows

—flexibility in the location of supply outlets and return grilles to obtain distribution of air for comfort

—positive circulation of air and comfortably uniform temperature distribution with humidity control readily attained
—a properly designed distribution system both for winter heating as well as summer cooling
—controlled quantities of ventilation air may be drawn into the system and conditioned before being introduced into occupied portions of the structure, recirculated air can be treated as necessary to obtain the desired quality

3.8.7 Absorptive Refrigeration

A description of the absorptive refrigeration system merits inclusion in this section on heating and cooling in view of the fact that it does not require high grade energy to drive the compressor For this reason it is a system that can be used in conjunction with solar collectors or waste heat recovery

3.8.7.1 Description

Description: The absorptive refrigeration system is a water chilling package which uses heat directly without the use of a prime mover, thus utilizing the heating facilities on a full time, year-round basis It uses the cheapest, safest and most available of all refrigerants, ordinary tap water Its absorbent is a simple salt solution such as lithium bromide. The absorption process varies from mechanical refrigeration in so far as the absorption cycle uses a heat-operated generator to produce the pressure differential whereas the mechanical compression cycle uses a prime mover driven compressor The absorption cycle substitutes a physico-chemical process for the purely mechanical processes of the compression cycle, and the mechanical energy required in the latter is substituted by the heat energy in the absorption cycle In the most common type of water-cooled equipment lithium bromide-water is used, with water being the refrigerant

The reader is also referred to Section 3.10.5 for a description of a typical solar operated absorptive refrigeration system.

3.8.7.2 Applications and Energy Considerations

Applications and Energy Considerations: Because of its compactness and vibrationless operation (no heavy moving parts), this system can be installed anywhere space and a heat source is available, from basement to roof, provided the floor is of adequate strength and level Since heat in the form of steam or hot water is generally the operating force of an absorption machine, the following energy considerations will favour its application

—where low cost fuel is available
—where electric rates are high
—where low pressure heating boiler capacity is largely used during the cooling season
—when waste steam is available
—where there is a lack of adequate electric facilities for installing a conventional compression machine. (Since the absorption machine uses only a small fraction of the electric power required by compression type equipment, its use becomes attractive where emergency standby power is required, as in hospitals.)
—absorption machines may be applied also in conjunction with gas engines or turbines and with centrifugal machines as combination systems for large tonnage applications, this results in considerable energy conservation and minimum heat rejection, permitting a smaller size cooling tower in large building complexes, condensation of steam from a back pressure steam

turbine in an absorption machine eliminates the need for a more expensive condensing turbine and steam condenser
—solar energy or the waste heat from a gas engine may be used as the heat source for the absorption machine

3.8.8 Air Conditioning Systems and Energy Conservation[13]

An overview of the different types of air conditioning systems which are available has already been presented in Sections 3.8.1, 2, 3 and 4. A comparison of the systems most widely used, including cost and energy consumption characteristics, is shown in Table 3.8.8-T_1.

Due to the complexity of the interrelated considerations among these systems, inevitably this tabulated summary is very general in nature

Each space or building presents an individual challenge for energy savings—there is no universal solution In every instance the designer must have a thorough understanding of the inter-action of space or building with external and internal thermal loads and with the contemplated air conditioning system Energy conservation requires that the building, the system and its controls form one integrated whole

The table below compares the principal features of the most commonly used systems

AIR CONDITIONING SYSTEMS					
Systems	Initial Cost	Energy Con-sumption	Control Cap-ability	Flexibility	Main-tenance Cost
Constant Volume—terminal reheat	average	highest	excell	poor	average
Constant Volume—terminal reheat, interior with perimeter induction or fan coil units	high	high	excell	poor	high
All-air induction with perimeter reheat	high	medium	good	fair	average
Constant Volume—double duct	average	high	good	fair	low
Variable Volume—terminal reheat	average	medium	good	poor	average
Variable Volume—double duct	average	medium	good	fair	low
Variable Volume—perimeter radiation heating	low	low	fair	good	average
Variable Volume—perimeter constant volume	low	low	fair	good	low
Variable Volume—induction with perimeter air or radiation	low	low	good	good	average

Table 3 8.8-T_1
Comparison of commonly used air conditioning systems

3.9 Ventilation

3.9.1 Introduction

This Section describes the introduction of outside air, of a satisfactory purity standard, to space within a building. Recirculated air is not ventilation.

The purpose of ventilation is to·

—provide adequate dilution of carbon dioxide levels created by the occupants
—provide adequate dilution of odours released by the occupants
—provide dilution of odours released by the building materials and fabrics
—remove or dilute odours and air contaminants resulting from activities and processes in building
—control condensation
—prevent moisture build-up in walls
—provide 'free cooling'

Outside air which contains a high level of contaminants requires special treatment in order to reduce them to an acceptable level

The establishment of correct ventilation rates is extremely important since energy required to heat and cool ventilation air can be 50% of total heating and cooling requirements Excessive ventilation, during cold weather, also creates humidification needs which increases energy consumption

3.9.2 Artificial Ventilation—Air Change

Artificial ventilation is the introduction and distribution of air by mechanical air moving systems Most buildings, other than residences, require mechanical systems to filter, condition, and distribute outside air in a satisfactory manner

Exhaust systems which remove air from areas of contaminant generation are part of the artificial ventilation process Where contaminant generation is concentrated, such as in kitchens or laboratories, local exhaust systems are required. Kitchens require hoods over cooking apparatus to capture odours, heat and other contaminants for removal. Laboratory processes that produce fumes are contained in fume cabinets which are exhausted to the outside

General exhaust systems are used to provide ventilation in areas such as washrooms, laboratories, beverage rooms, animal rooms, surgery support rooms, and various industrial process areas.

The minimum ventilation rate required to maintain oxygen levels and dilute carbon dioxide is 2 5 L/s per person The minimum recommended ventilation rate for manual activity such as office work, residences, assembly rooms and the like where a limited amount of smoking takes place is in the order of 5 L/s per person. Ventilation rates of 12 5 L/s per person are recommended in facilities in heavy smoking areas such as beverage rooms, cocktail lounges, and board rooms.

Mechanical systems have the capability of distributing air in predetermined quantities throughout a building. This can provide adequate ventilation without excess in some areas and insufficient ventilation in others. Energy is required to condition and distribute ventilation air, and this energy consumption can be minimized if the correct amount of air is delivered to each room or area within a building.

Ventilation air is often mixed with recirculated air, in air moving apparatus, and delivered to conditioned areas as part of the total air

supply. The advantage of this process is that distribution of ventilation air is maximized since it is a part of a much larger quantity of circulated air

Refer to Table 6 Chapter 21 of ASHRAE Guide Fundamentals Handbook

This table lists required ventilation quantities for 100% outdoor air of quality meeting the standard If adequate temperature regulation is provided, and filtration restricts particulates to 60 $\mu g/m^3$ the outdoor air may be reduced to 33% of the listed quantity If in addition efficient adsorption or other odour and gas removal equipment is provided it may be reduced to 15% Minimum outdoor air quantities however should be no less than 2 5 L/s per person Central air distribution systems which serve a multitude of rooms or areas create an averaging effect of the air quality This tends to offset migration of people from one area to another and this process often eliminates special provisions for occasional high population densities such as can occur in auditoria in schools, for example

3.9.3 Natural Ventilation

In an earlier Section, **Section 3.5.1** Physics of the Building Envelope it was noted how natural ventilation can be provided by both kinetic and thermal head convection The other significant forces in this regard are wind pressure and stack effect and these were described in **Sections 3.3 3** and **3.3.4**, respectively

The following discussion focusses upon some of the practical problems which presently limit the application of natural air movement as a means of building ventilation

3.9.3.1 Practical Considerations

Despite the important physiological effects achieved when natural ventilation is employed in a building structure, it is obvious there can be drawbacks These include dust, noise and the fact that in many cases the scale of the project makes its use impractical

Natural ventilation introduces outside air without filtration and conditioning This is undesirable in most retail and office space, where temperature control and cleanliness without occupants' attention is the norm

However, there are periods of the year in the spring and fall when the temperature of outside air is such that its direct introduction to a building for ventilation purposes is feasible Under these conditions ventilation openings that allow a natural flow of air to locations in the structure can be utilized This situation would normally apply to residences and small scale industrial buildings

Larger scale buildings such as offices, hospitals, nursing homes, shopping malls, etc where the ratios of floor area to outside skin are high do not adapt so simply to natural ventilation systems The problem is that they are not controllable to the degree required to achieve the desired space condition.

There is not normally any reliable steady state condition that the designer can use as a base point. The internal heat generated in larger scale buildings by lights and people requires a controlled introduction of ventilation and recirculated air to maintain comfort conditions.

This orderly introduction of air of a known energy level is most difficult to achieve with outside air Despite this, designers should explore the feasibility of natural ventilation systems as much as possible In this connection, the reader's attention is drawn to Section 5.5.4.3 regarding wind energy and its potential for the ventilation of buildings

Figure 3.9.3.1-1 shows relationships of air flow due to combined wind and stack effect When air flow caused by indoor-outdoor temperature difference equals the air flow caused by wind effect the actual flow of air is 30% greater than the flow caused by either force.

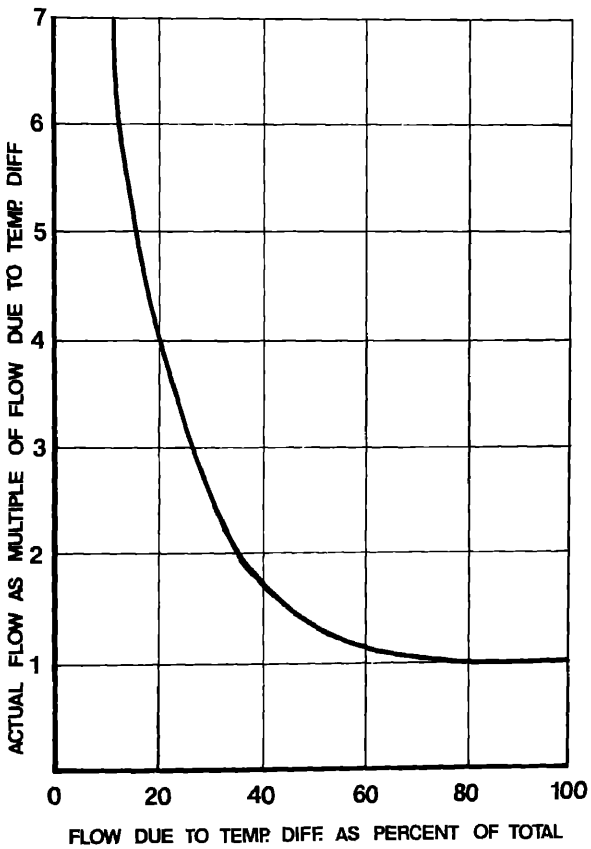


Figure 3 9 3 1-1
Air flow relationships due to a combined wind and stack effect

3.9.3.2 Cross Ventilation

A simplified calculation of the potential rate of cross ventilation can be obtained from the following formula:[1]

$$Q = 166\,AV$$

where:

Q = rate of airflow, L/s
A = area of inlets, m^2
V = wind velocity, km/h

Where the area of the outlet is appreciably different from that of the inlet, the expression requires adjustment, as follows

Area of Outlets: Area of Inlets	Value to be substituted for 166 in above expression
1.1	166
2 1	210
3 1	223
4 1	281
5 1	231
3:4	142
1.2	105
1 4	52

Figure 3.9.3.2-1 is a graphical indication of the percentage increase in air flow caused by unequally sized inlets and outlets

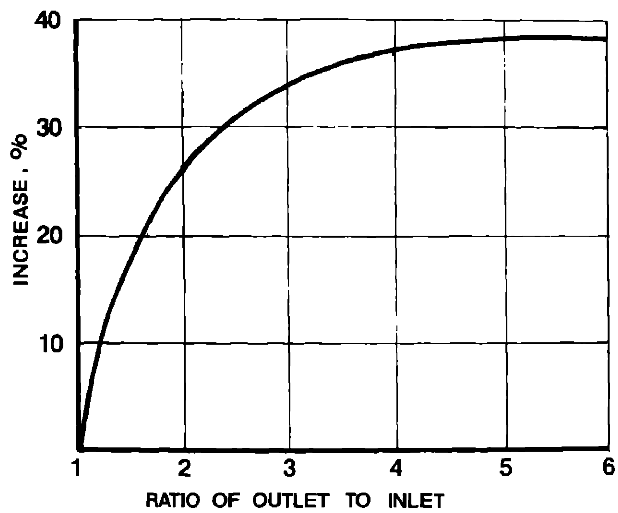


Figure 3 9 3 2 -1
Air flow relative to outlet and inlet

The value of the stack effect (for example in a house with a clerestory and operable windows) can be estimated from the following formula [2]

$$Q = 111\, A \sqrt{H(t_i - t_o)}$$

where

Q = rate of airflow, L/s
A = area of inlets, m^2
H = height between inlet and outlet, m
t_i = average temperature at height H, °C
t_o = temperature of outdoor air, °C

Again, where the area of outlets is appreciably different from the area of inlets, the expression requires adjustment. The substitutions, relative to area ratios, are as follows:

Area of Outlets: Area of Inlets	Value to be substituted for 111 in above expression:
5	154
4	153
3	149
2	140
1	111
3/4	93
1/2	69
1/4	37

For many residential uses in Canada, appropriately designed, natural ventilation from wind and density flow will be quite adequate.

In some climatic zones this could be beneficially supplemented by window or attic fans. Where room height permits their installation, 'Casablanca' fans also can provide useful ventilation and they are finding employment in industrial, commercial and other types of building in addition to residential

Fans should be located to serve as large an area as possible and their relation to other openings carefully considered so that short-circuiting is avoided.

Figures 3.9.3.2-1 and /3 illustrate how air flow through a building is affected by location of openings and external architectural elements.

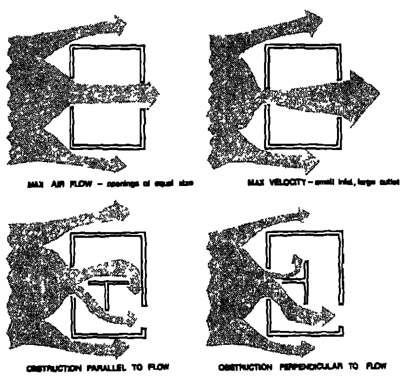


Figure 3 9 3 2-2
Internal flow patterns, floor plans [3]

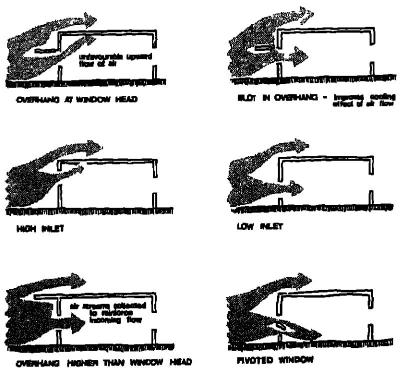


Figure 3 9.3.2-3
Internal flow patterns, sections [4]

3.9.3.3
Possible Applications

Some unconditioned industrial plants can accept dust, variable temperature and humidity conditions characteristic of outside air. In such circumstances, removal of heat generated by equipment and process can be achieved, to some extent, by natural means.

Natural ventilation is common in residential occupancies where occupant control of windows and other manually operated openings is accepted practice. In this application, natural ventilation openings are closed when outside air conditions are unfavourable to comfort and cleanliness within the occupied space.

Winds create an uplift or negative pressure on a roof which can also be used to generate air movement out of a building. Figure 3.9.3.3-1 indicates how typical forces and air currents interact in an industrial building when there is no wind pressure.

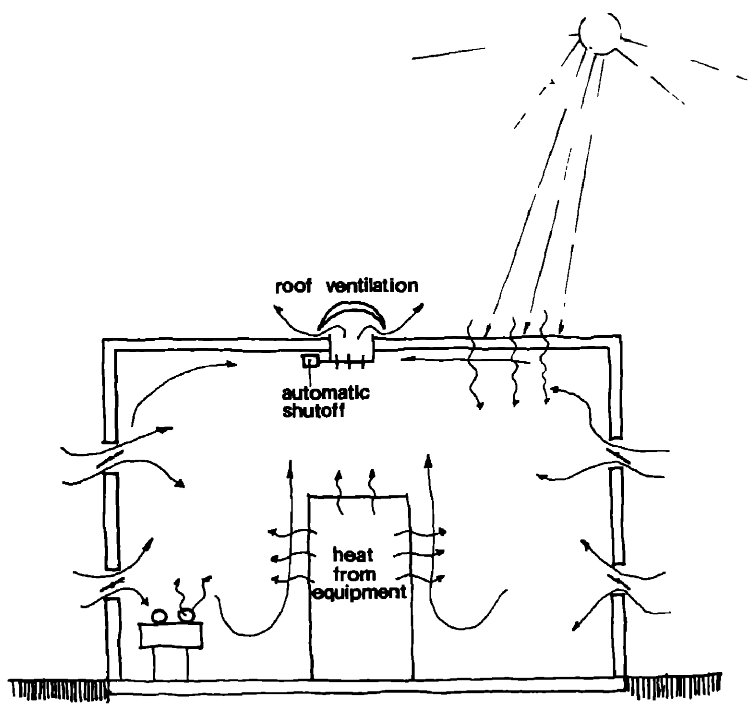


Figure 3.9.3.3-1
Natural ventilation system for an industrial building

3.9.3.4
Natural and Artificial Systems

Natural and artificial ventilation systems are not normally compatible. The drawbacks inherent in the application of both systems within a single structure are size and location of openings.

Although these openings could be adjusted manually or automatically when one or the other type of system is being utilized the duplication required is seldom practical. Additionally, in the extreme Canadian climate, an opening is a potential source of heat loss or gain. High standards in the construction and installation of air inlets and outlets are essential if natural ventilation is to produce significant net energy savings.

3.9.4 Air Flow Controls and Structural Provisions

The distribution of air throughout an occupied space is one of the more important factors affecting comfort. Clean conditioned air is delivered from the source fan system and terminates in an air flow control device mounted in the space. These terminals can vary from relatively simple grilles and diffusers to more sophisticated linear slot types Each air flow control device must be selected for a specific purpose in order to achieve the desirable comfort conditions in the particular space

Ceiling diffusion provides the best results in most applications where supply air is introduced at temperatures below the space temperature setting. Introduction of supply air at this location can be achieved in several ways Some of the most common being as follows

—circular diffusers which distribute the supply air at the full 360° perimeter of each diffuser, or through any sector of the circumference that is required

—square or rectangular diffusers which can be selected as uni-directional, two way, three way or four way air supply devices

—slot type units which can be separate or combined with light fixtures in several combinations.

The function of all diffusers is to distribute the air at predetermined velocity, in sufficient and at acceptable sound level to maintain the required space temperature At the same time they must not cause occupant discomfort via drafts or allow the higher density cold air to drop directly to the comfort zone of the space The air being introduced must entrain the room air and cause continuous circulation through the space. (See **Figure 3.9.4-1**).

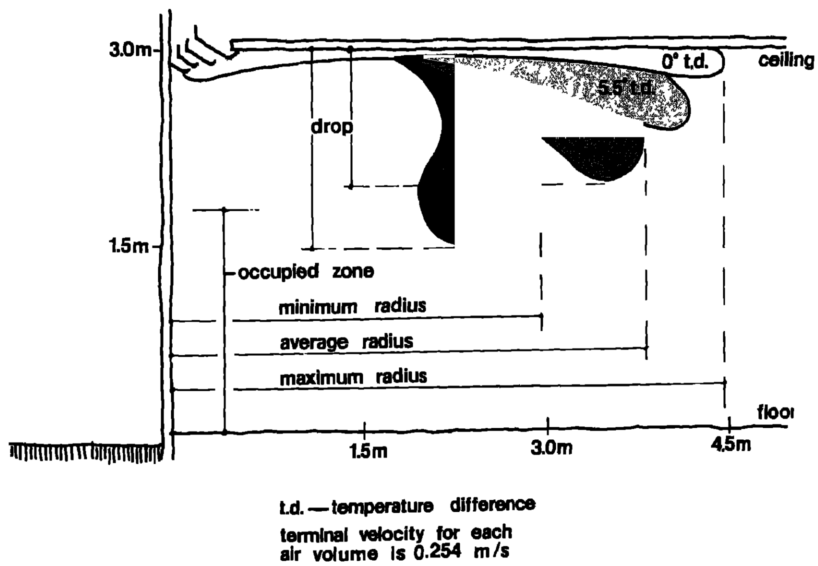


Figure 3 9 4-1
Ceiling distribution pattern

Other air control devices include:

—grilles with volume dampers and directional vanes which are installed on vertical rather than horizontal surfaces

—turning vanes in supply duct work which reduce turbulence and pressure drop

—air terminals or air valves which control the amount and/or the temperature of air being supplied to grilles and diffusers.

Installation of air supply devices on vertical surfaces in many instances mandatory for some areas is not normally as satisfactory as ceiling diffusion supply because it is more difficult to obtain complete coverage of the total space, see Figure 3.9.4-2. Introduction of air supply at window sill line is commonly used and will result in good air distribution when properly selected for perimeter areas of most buildings, see Figure 3.9.4-3.

As stated previously, the goal of all designers in air distribution must be to achieve equal coverage and air movement in all areas of the space involved without creating drafts and within acceptable noise criteria.

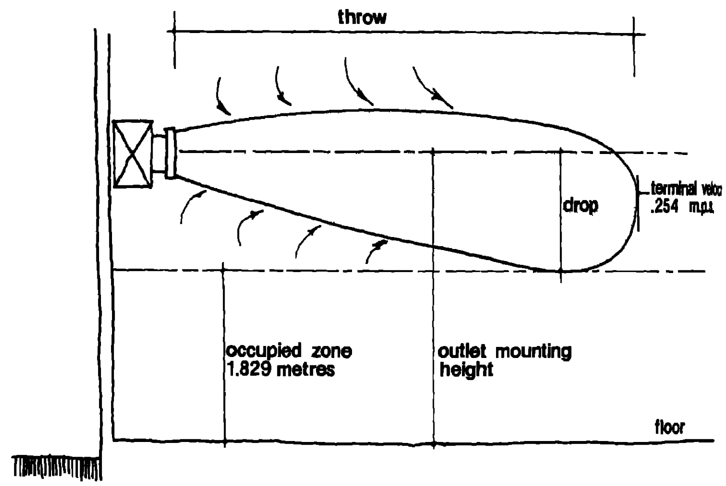


Figure 3.9.4-2
Horizontal air supply distribution pattern

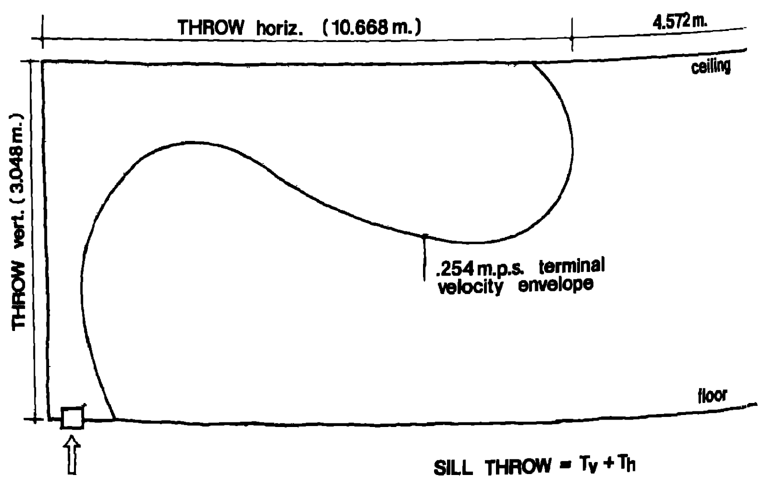


Figure 3.9.4-3
Sill air supply distribution pattern

3.9.4.1
Energy Conserving Features

In recent years air control devices that vary the amount of air being delivered to the diffuser and thus to the space, have been increasingly employed in the industry These variable air volume terminals have considerable advantages in terms of energy conservation. They provide the ability within the system to automatically control the space temperature by varying the amount of air supplied to the space, without wasteful over-supply. They also allow certain economies in the air system fan power energy requirements.

Care must be taken to ensure that the static type air diffusers used with these variable volume terminals have stable air distribution patterns at volumes up to 75% less than their maximum air delivery If air discharge velocity is too low, cold air will drop to the floor, rather than flow in a horizontal plane. Normally this problem will not occur if the diffusers selected are small enough to allow proper performance at the minimum design air flow as determined from test data

3.9.4.2
Fan Rooms

Constructional provisions for space required for air delivery are normally very specific for each project. Provisions must be made for fan rooms which require outside walls and roof openings for air intake and exhaust and for distribution ductwork or conduits within the structure Many variables affect these requirements such as type of structure, i.e (steel, wood, or concrete or any combination of these), height of structure and of course the function of the building Care must be taken to reduce vibration and noise transmission to the space immediately surrounding the fan rooms and to the structure itself through the duct distribution system

Fan rooms are ideally located at the centre of the space being served Economies in duct sizing and electrical energy consumed, due to lower pressure drop in shorter duct runs, can be achieved if conditions allow this ideal location. Generally, air is cleaner at the high point of a building especially in a city environment and therefore air intakes at the roof are a good location Satellite fan rooms i.e a number of mechanical rooms located remote from the central apparatus are often necessary. The same rules mentioned above apply to these situations

3.9.4.3
Ductwork

Air can be transported in low pressure, medium pressure or high pressure ductwork. Many factors must be considered in order to make the correct choice The higher the pressure of delivered air the smaller the duct space requirements. Unfortunately severe first cost additionas to eliminate noise and higher operating costs and involved that must be justified Fan power requirements increase as the cube of the air pressure delivered by the fans

Generally a given design must provide an area of free space to distribute ductwork. Interference with other building components must be solved during the design process and this fact has to be understood by all design team members

3.9.4.4 Space Requirements

The following are general rules for space requirements for air distribution systems in buildings Actual requirements however will depend on a detailed engineering analysis

—The total size of shafts for ductwork will be 0 03% to 0.04% of the floor area in a multi-storey building

—The space required for the central mechanical facilities housing the boilers and refrigeration plant will require an allowance of 2% of the gross building area.

—Fan rooms require from 2% to 4% of the gross building area. assuming that the central cooling and heating equipment is installed remotely from the fan rooms

—In high-rise structures particularly, individual fan rooms per floor, or pair of floors will achieve the most efficient use of space and energy These locations versus centrally located roof and mid-point of building fan rooms should be considered for tall buildings This efficient placement of individual fan rooms is predicated on the proper design of heat reclaim and water to air free-cooling systems The installed power and therefore energy consumed is less under these conditions because the duct pressure drops are lower for a given air quantity Much shorter duct runs are required and air distribution can be utilized

—A basement fan room may occupy 20% more space than one above grade because of outside air intake and exhaust plenums and shafts.

3.10 Solar Energy Technology

An earlier Section of the Handbook (2.1.2 General Climate) prepared by the Atmospheric Environment Service, indicated the significant and useful quantities of solar energy that are available throughout most of Canada In addition to radiation measurements for representative locations, the reader was also given a method of calculating the contribution that passive solar collection can make to meeting space heating requirements.

Clearly, architects can, and must, take advantage of this virtually inexhaustible resource which can be readily utilized in thoughtful, energy conserving design.

A solar building can be said to be different from a conventionally heated one in the following ways:

—It collects the sun's heat that falls upon the building's surfaces
—It stores solar heat so that it can be used during the night or during sunless days.
—It distributes stored solar heat throughout the building for comfort
—It retains heat in the building by reducing or eliminating usual sources of heat loss

All buildings that are exposed to the sun are solar heated to a greater or lesser extent

The following pages describe 'passive' and 'active' systems and summarize how they may be employed for space and water heating Their implications for building design and construction are also examined. The reader should keep in mind that at this stage in development there are no 'standard' solutions, each particular situation should be judged on its own merits and the systems selected must be based on careful calculation

3.10.1 Passive Solar Systems[1]

Passive solar heating is space heating derived directly from solar energy. No fans, pumps or other mechanical devices are involved, the thermal energy flows entirely by natural means

3.10.1.1 Introduction

A passive solar system can provide a significant percentage of a building's space heating requirements. Moreover the resultant savings in conventional forms of energy can be obtained with limited investment. Briefly, such savings arise from architectural design which recognizes the inter-relationship between building and natural environment, between the thermal characteristics of constructional elements and sun and climate

Passive solar heating is not a separate mechanical system but an integral part of a building—'the building is the system'. The architect is in an unique position to implement passive solar design both at the planning and detail stages of specific projects.

The advantages of a passive solar system compared with an active one (ref. Section 3.10.2) include the following:

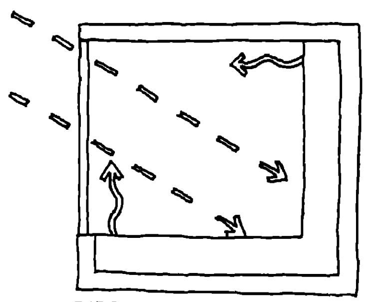
—lower initial capital cost
—less ongoing maintenance.

Effective passive systems generally require more involvement of the inhabitants of a building, for example in the operation of blinds or shutters, than the more automated active solar systems. Addi-

tionally, the control of comfort condition requires a high level of architectural design sophistication because of the absence of mechanical assistance

Three passive solar systems appropriate for Canadian climatic conditions are defined as follows
—direct system
—mass wall system
—attached sun space system

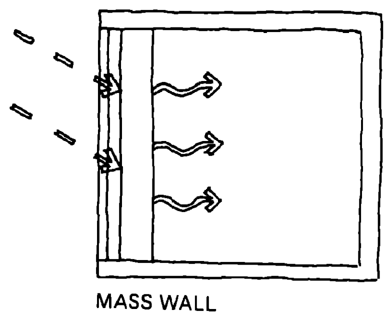
Usually, the path of thermal energy flow is from a collector (glazed area) to storage (time lag of building mass) to living space The particular characteristics of the three systems are summarized in Figure 3.10.1-1.


DIRECT

Definition· The building space is directly heated by the sun, the solar heat is stored in the mass of the house

Requirements· South facing glass wall usually double or triple glazed to prevent heat loss

Wall floor or ceiling mass with solar exposure and significant capacity for thermal storage

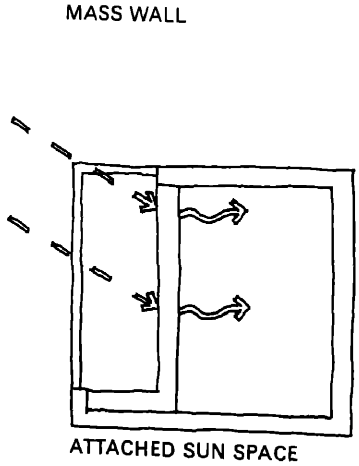

MASS WALL

Definition· A glass covered mass collects and stores solar heat directly from the sun and then transfers heat to the building space at a time lag e g Trombé wall

Requirements· South facing glass wall usually double or triple glazed to prevent heat loss

A thermal storage mass directly behind the glass wall

Optional reflective device to concentrate solar radiation


ATTACHED SUN SPACE

Definition· Solar collection and storage form a space that is thermally isolated from the building space as in a lean to greenhouse, a glazed atrium, or a sun porch The building draws from this space as the comfort requirements dictate

Requirements South facing, glass enclosed collection space thermally linked to a thermal storage mass, floor walls, benches, rock beds, water tanks

This solar collection space must be attached to the house, yet distinct

Optional reflectance device to concentrate solar radiation on glass

Interface to building for radiation, convective or conductive heat gain

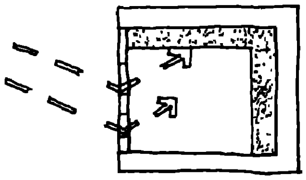
Figure 3.10.1-1
Passive solar systems.(2, 3)

3.10.1.2 Constructional Provisions

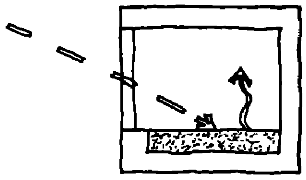
The constructional provisions for the three types of passive solar system will be discussed under their respective headings.

.1 Direct System. Figure 3.10.1.2-1: This is a relatively low cost system as the solar collector is the window. The storage mass, either interior elements or exterior walls, insulated on the outside, reradiates heat to internal spaces. Protective overhangs are essential at glazing to avoid summer overheating

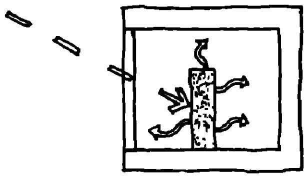
SECTIONS



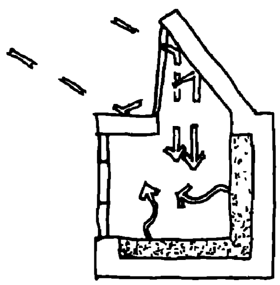
A. reflective device for ceiling



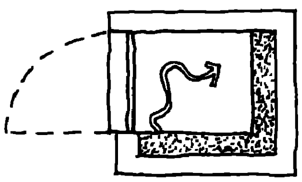
B. floor storage



C. mass in lightweight construction



D. roof monitor



E. insulating device

Figure 3.10.1.2-1
Direct systems [4, 5]

Storage Mass: usually concrete or masonry but can be water tanks or additional drywall or plaster

Variations: storage mass usually provided by walls and floors related to south glass wall, solar roof monitors for north wall and floor

Controls:

—sun shading (awning, overhang, curtain, blind) to prevent unwanted heat gain and glare
—insulating devices for the glass wall will diminish night time heat loss
—adequate summer time ventilation is required

Design and Performance, Characteristics

(i) Advantages
—architectural design flexibility
—standard materials available
—low maintenance
—convenient to operate
—relatively low cost as solar glass wall is also house window
—provides bright area for plant growth internally
—collection glass area also provides light to living space

(ii) Disadvantages
—building orientation dictated by sun position except for roof monitor
—glare and overheat without controls
—ultraviolet degradation and fading of fabrics without controls
—controls are necessary and must be well designed
—conventional construction has low thermal mass
—solar collection temperatures are limited by occupant comfort needs
—external thermal mass walls roofs are expensive to insulate compared to conventional light construction.

.2 Mass Wall System. Figure 3.10.1.2-2: This system utilizes an exterior storage mass, with appropriate time lag, which will provide heat to the interior by radiation or convection

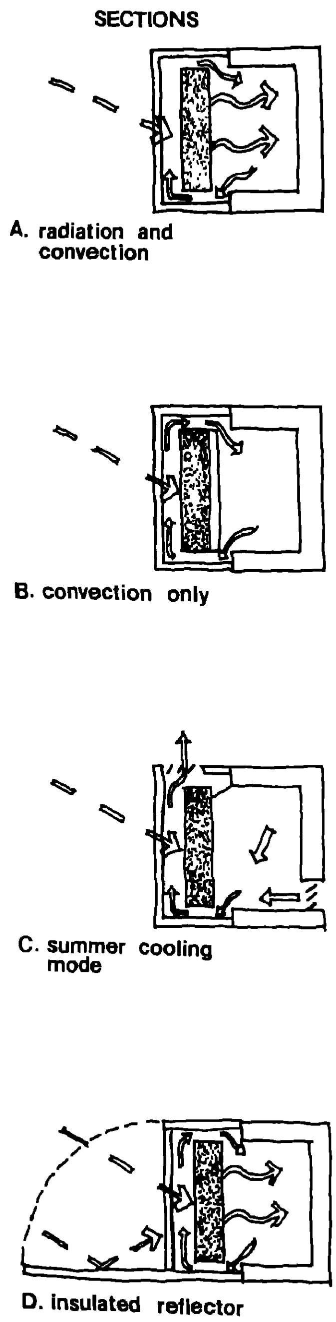


Figure 3.10 1 2
Mass wall systems (6, 7)

Storage Mass. usually concrete, stone masonry, or composite of brick, block sand but can be water or phase change materials in tanks or tubes

Variations: vents at top and bottom of mass are optional-Trombe wall Other names for walls which provide thermal storage capacity are drumwall and tube wall, depending on storage containers used

Controls
- —well designed time lag with properly selected heat storage capacity and emission properties related to living space
- —dampers at top and bottom of thermal storage mass to control convective heat into the living space are optional
- —internal insulating device to control radiation from thermal storage mass
- —optional exterior insulating device on glass wall to diminish night time heat loss
- —optional exterior sun shading to prevent unwanted heating of thermal storage mass
- —optional exterior vents for summer cooling mode

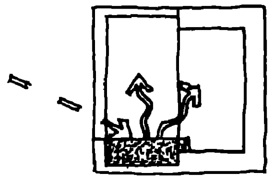
Design and Performance, Characteristics

(i) Advantages
- —low maintenance
- —better protection from glare than direct system
- —time lag between collected energy and distribution to living space
- —controls less crucial than direct because of storage lag
- —thermal mass can be integrated into light construction design

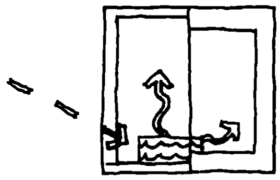
(ii) Disadvantages
- —building orientation dictated by sun position
- —restrictive architectural design, particularly reducing direct natural solar gain and bright spaces for occupants and household plants
- —controls and thermal storage mass must be well designed
- —capital costs associated with glass wall, storage mass, controls

.3 Attached Sun Space System. Figure 3.10.1.2-3: The addition of a glassed space (greenhouse) on to an existing dwelling has obvious retrofit capabilities It could be integrated into house design in the form of an atrium or glazed court. There is also the opportunity for year round fruit and vegetable production.

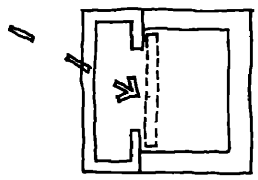
SECTIONS



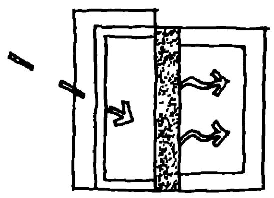
A. massive floor



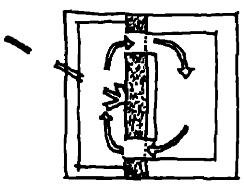
B. water mass



C. movable insulating wall



D. massive wall and movable insulation



E. massive wall and convective heat gain

Figure 3.10 1.2-3
Attached sun space systems (8, 9)

Storage Mass: existing wall face, floor, additional facing to wall or water reservoir

Variations· related mainly to the interface with the house, minimum addition to house or entire south wall of house, can be integrated into house design (atrium or glazed court) or added as a lean-to

Controls
—sun shading (awning, overhang, curtain, blind) to prevent unwanted heating of glass space
—insulating devices for the glass wall will diminish night time heat loss
—insulating devices to control radiation and conductive heat gains into house
—dampers to control convective heat gain into house
—adequate summer ventilation of house and sun space
—humidity control between glass space and house if plants are grown

Design and Performance Characteristics

(i) Advantages
—retrofit capabilities (reduces infiltration and conduction)
—plant growing capabilities
—house orientation not dictated by sun position
—architectural design flexibility.

(ii) Disadvantages·
—large glass surface to insulate if greenhouse is to be a useful space
—capital cost of glass space
—costly thermal control of, heat gain and heat loss from glass space
—additional volume of glass space requires additional heating requirements if it is used for plants
—snow problems if sloped glass roof is required
—higher maintenance
—glass space dictated by south orientation.

3.10.1.3
Costs and Efficiency

Though there is a general lack of documentation on costs for passive systems it is apparent that they vary considerably depending on the type of design.

In 1979 a typical active system could add between 20% to 30% to the cost of a medium sized residence and achieve a 50% to 70% reduction in heating bills. Passive systems increased the cost of a medium sized house by 10% to 15% and achieved about 30% to 50% reduction

Obviously, the cost is dependent on which elements of the construction are attributed to the system and which to the building As passive features should be an integral part of future building design, even if active systems are also employed, calculations of extra cost involved will depend upon the degree to which the passive approach is developed For example, orienting most residential windows to the south in a cold climatic region can achieve dramatic reduction in energy requirements without any additional cost—providing this was intended in the original design

3.10.1.4
Design Tools

The art of passive solar design is dependent on many environmental parametres, such as climate, ambiant temperature and desired building environment The heat loss characteristics of a particular building type and how it is used by the inhabitants can alter these design requirements The judicious balance of glass area (collector) with building mass (storage) is presently being formulated in both the United States and Canada[10, 11] Guides to the design of passive solar residential buildings are beginning to present usable formulae[illegible]

While collection of solar heat is the objective, it should be noted that passive solar design must also avoid the problems of over-heating which can occur if large areas of glass are not shaded in the summer and if appropriate cross ventilation is not provided

3.10.2 Active Solar Systems

If mechanical assist is required for heat transfer from collector to the storage and from storage to the living space, it is defined as an Active System

Active solar systems consist of three components
—collector
—storage
—distribution

A simplified diagram of an active solar heating system is shown in Figure 3.10.2-1.

Most active solar systems are either based on liquid or air as the thermal transfer medium (Ref. Sections 3.10.3 and 4)

Water has a higher thermal storage capacity per unit volume while air systems do not have the freezing problems associated with liquid systems.

Computer programmes are available for designers as an aid in selecting the most appropriate solar system. Programmes can estimate solar system performance for different locations, heating loads, solar system configuration and collector type and orientation. The

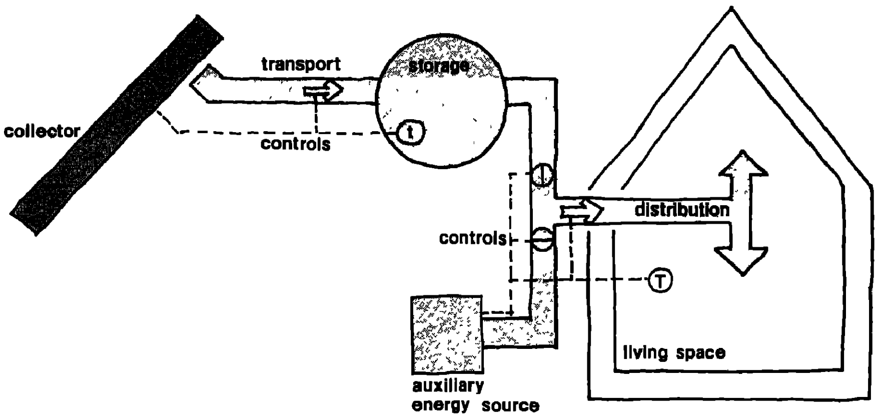


Figure 3 10 2-1
Active solar energy system

most commonly used programmes for standard solar systems designs are the F CHART and SOLCOST programmes. Both are available to users on the Control Data Cybernet System.

3.10.2.1 Types of Collector

The collector converts incident solar radiation to usable thermal energy by absorption on a dark surface. The thermal energy captured is transferred to a heat transfer medium, usually gas or liquid

There are two common types of collector
—flat-plate collector
—focusing collector

.1 **Flat-Plate Collector:** The relatively simple flat-plate collector has found widest application in buildings. It utilizes direct as well as diffuse radiation This type of collector consists of an absorber plate, often aluminum, steel, or, usually, copper, which may be flat or corrugated, with a black surface to increase absorptivity of the sun's heat. It is insulated on its back to minimize heat loss from the plate and is covered with a transparent glass or plastic which provides the solar greenhouse effect. The captured solar heat is removed from the absorber plate by means of a working fluid usually air or treated water.

All flat-plate collectors take advantage of the green house effect in which short wave radiation passes through glazing and is absorbed by the blackened plate. Infra-red radiation is then trapped behind the glass plate Thus, solar flat-plate collectors are often called heat traps.

There are three types of flat-plate collector and innumerable variations, namely: trickle collector, air collector and liquid collector.

—Trickle Collector: This is the least expensive type of collector. It consists of corrugated metal roofing panels which are painted black and covered with a transparent cover-sheet. The corrugation provides open troughs for trickling water which is fed from a supply at the top of the roof and collected at a gutter at the base.

Trickle collectors are difficult to employ in cold climates because of condensation problems and the corresponding loss of efficiency. Figure 3.10.2.1-1.

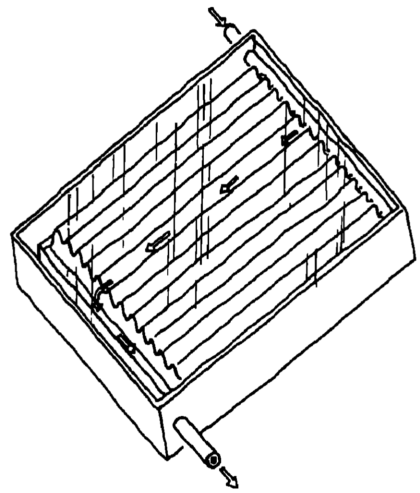


Figure 3.10 2 1-1
Trickle collector

—Air Collector: Low maintenance and relative freedom from freezing problems are two of the chief advantages of air collectors The air flows either above or below an absorption panel, usually folded or articulated, and when heated can be passed directly into the building space or into a storage bin. Disadvantages are the inefficient transfer of heat of the air when compared with a liquid collector. Figure 3.10.2.1-2 and 3.

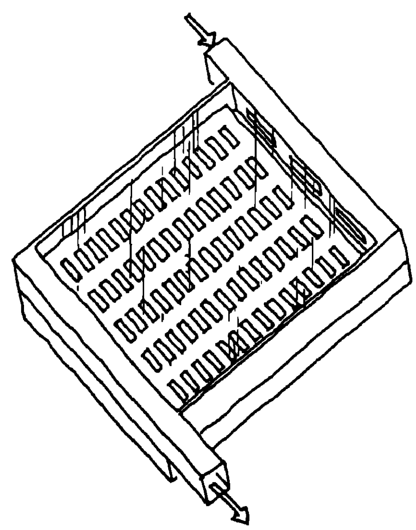
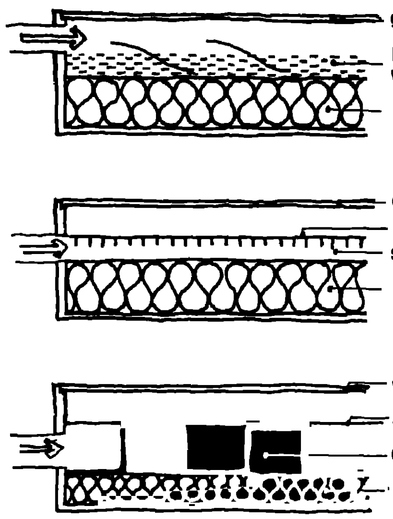
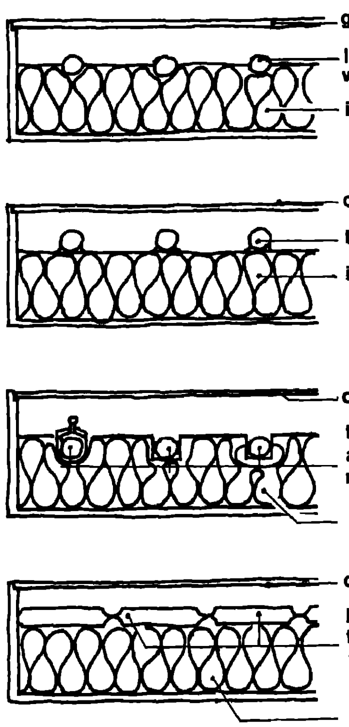


Figure 3.10.2.1-2
Air collector.[13]



A Air collectors



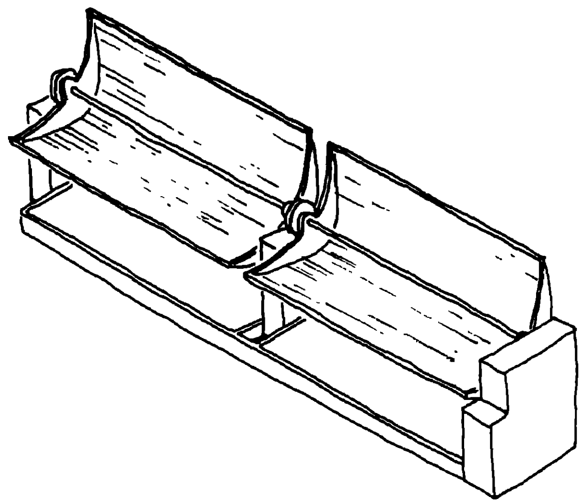
B Liquid collectors

Figure 3.10.2.1-3
Air and liquid collectors, cross section.[14]

—Liquid Collector: Probably the most popular collectors on the market today are the liquid collectors which use liquid, (ref **Section 3.10.3**) as a transport medium. The liquid is heated as it passes through the absorber plate of the collector and is then transferred to the storage tank. The prevention of freezing, corrosion and leaks have been the major problems that have plagued this type of collector. **Figure 3.10.2.1-3.**

.2 **Concentrating Collector**: This type of collector uses a curved target reflector to increase radiation on a small target area such as a tube. Concentrating collectors have a higher cost than flat-plate collectors with added problems of reflective surface maintenance They produce higher temperatures and therefore are often used in conjunction with absorptive cooling systems. Concentrating collectors are best suited for areas with clear skies because of their inability to function on cloudy or overcast days.

—Linear Concentrating Collector· In this collector, heat is removed from the absorber by a working fluid circulating through a pipe which is the target The working fluid should have a boiling point above the expected operating temperatures of the collector and must also resist freezing. **Figure 3.10.2.1-4.**



LINEAR CONCENTRATING COLLECTOR

Figure 3.10.2 1-4
Linear concentrating collector

—Evacuated Tube Collector: Concentrating collectors must track the sun throughout the day which is a decided disadvantage. A recent innovation which avoids this problem is the highly efficient evacuated tube type collector in which small absorber tubes with black glass enamel form the target inside the cover tube with a heat-reflector surface.

3.10.2.2 Location of Solar Collectors

There are three locations for the placement of solar collectors in active systems, namely; detached, attached or integrated with the building.

Collectors may be integrated with the walls, roof or detached by placement on the ground or on an ancillary structure.

Collector orientation is critical for the optimum exposure of the collector to solar radiation. Though research is not complete it indicates that a 20° variation either side of true south does not significantly alter the performance of most solar flat-plate collectors. Collector tilt is an important consideration. The tilt is determined by the geographic location of the building and the functional requirements of the solar system. Snow-fall characteristics may influence the appropriateness of the optimum collector tilt. For large amounts of annual snow-fall a tilt angle of 40° or more is considered to induce natural avalanche off the collector. The most mentioned rule of thumb is that latitude plus 15° is required for heating in colder climates such as Canada. Reducing tilt may improve summer heat collection for domestic hot water heating, but at the expense of winter collection.

Care must be taken to locate solar collectors so that they are not in the shadow of adjacent buildings and landscaping. In most cases, the solar collectors are located on the building in the roof area because of cost considerations. Collectors weigh approximately 40 kg/m^2 to 50 kg/m^2.

3.10.2.3 Storage

The storage component of a solar system is a reservoir capable of storing thermal energy Insulated storage is required since there may be an energy demand during the evening or on consecutive sunless days when collection is not possible. Storage acquires heat when the energy delivered by the sun and captured by the collector exceeds that demanded at the point of use.

The ability of a material to store heat is a reflection of its density per unit volume and its specific heat. The storage medium is usually small pebbles for an air based system or treated water for a liquid system. Phase-change materials have been tried and hold promise but to date are not proven.

Two active system types are defined relative to storage·

—long term or annual heat storage

—short term of daily heat storage

Long term storage usually requires a large storage tank with associated insulation costs, while a heat pump is often used in conjunction with short term storage system.

The type and size of solar heat storage will have varying influences on a building design The most important design consideration for solar heat storage is inclusion in the building of a sufficient space for the often large volume associated with storage components. For example, water tanks may range from 2000 L to 800 000 L (the annual heat storage type). Savings accrue when the storage is associated directly with the building because of reduced insulation requirements.

There are two basic locations for storage, within the building or outside of it. The inter-relationship between the geometry of the storage and the size of the building, as well as structural considerations, will determine this location.

3.10.2.4 Distribution

The distribution component receives energy from the collector or storage and transfers it to the building. Heat is usually distributed in the form of warm air or warm water by ducts or pipes. Distribution of energy will depend upon the temperature available from storage. Water temperatures as low as 40°C may still be useful for space heating, if the baseboard convectors are increased in size or if a fan-coil unit is used.

Because solar produced temperatures in storage are normally in the low range, 40°C to 75°C, distribution ducts and radiating surfaces are normally larger than those used in conventional heating systems Careful consideration is required in the design of heat distribution systems throughout the building

3.10.3 Solar Liquid Systems

In the following review of solar liquid systems, the requirements for domestic and service hot water heating and space heating are examined.

The heat transfer liquids can be treated water, polypropylene, glycol solutions and silicon oils Since the collectors may be exposed to temperatures as low as −40°C and as high as 150°C or higher, the system must be protected from damage. When treated water is used the collectors are drained under extreme conditions. In order to minimize corrosion, great care must be taken in the choice of system components and heat transfer fluids.

Systems using liquids as the heat transfer medium usually use an insulated water tank for heat storage. The solar energy is used to heat the tank while circulating radiation water draws heated water from the tank and returns cooler water Approximately 50 L- 100 L of storage is used per square meter of collector area

A typical water heating solar system costs about $450/m^2$- $600/m^2$ of collector installed and provides about 2500 $MJ/m^2/a$.
This is equivalent to about $12.54 of oil at 1979 prices in Toronto A cost breakdown of such a system reveals that about a third of the cost is required for installing a collector support structure, in a retrofit application, and a further third for the plumbing, storage and controls while only a third of the cost is spent on the collectors themselves. Substantial cost reductions in new construction can be achieved by the following:

—including the collector support structure as part of the roof
—designing a solar system with no storage so that heat is delivered directly from the collectors to the end use when the sun is shining, this is feasible where there is a constant base load, if the collector array is sized to meet the load only on the most sunny days then all the energy supplied by the collectors will still be used.

These measures might result in a solar system costing only about $300/m^2$- $400/m^2$ of installed collector and still producing about 2500 $MJ/m^2/a$.

3.10.3.1 Domestic Hot Water Heating Systems

The most cost effective use of solar heating in Canada in 1979 appears to be for domestic hot water supply and swimming pool heating. With regard to the former, relatively simple packaged systems are now available which can provide a useful proportion of the heat for bathroom and kitchen water.

For an individual house, a typical system consists of one or two solar collectors and a close loop anti-freeze type heat exchanger which heats the water in a domestic hot water tank Back-up heating supplements the solar as required A recently developed design eliminates the closed loop; when there is danger of freezing the water is removed from the collector by forced air pressure

Figure 3.10.3.1-1 illustrates a solar water heating system suitable for a high demand application such as an apartment house or commercial premises

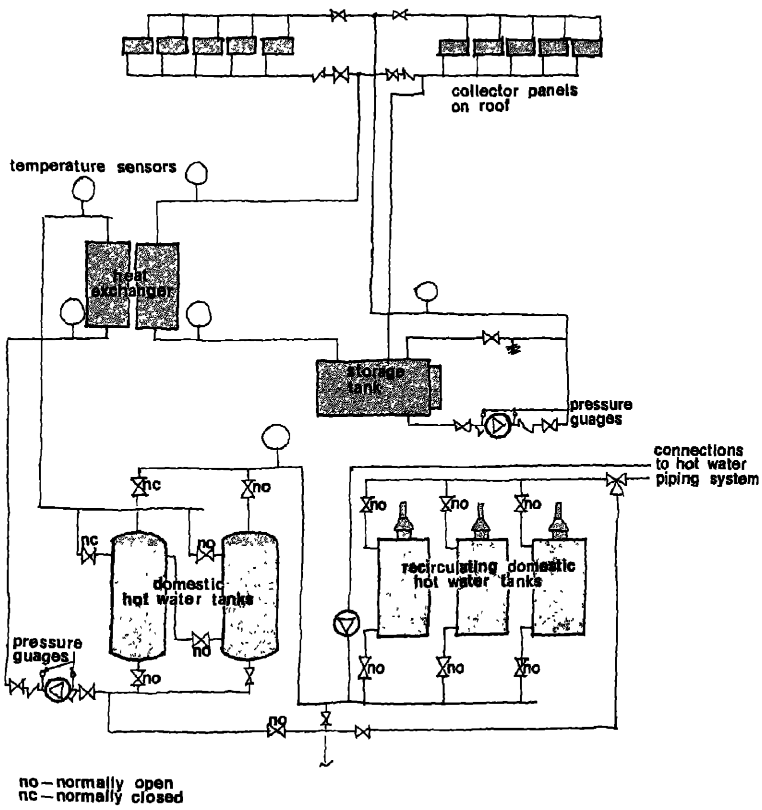


Figure 3 10.3.1-1
Solar water heating system, high demand application

Residential solar heaters for domestic hot water have been in use for a number of years in several countries including Japan, Israel, Australia and other warm temperate zones. The most commonly adopted has been the thermosyphon system which consists of one or more collectors stationed below an insulated storage tank. In this system the heated water in the collector expands and rises through piping to the top of the storage tank while the cooler storage water sinks down from the storage tank to the bottom of the collector. No controls or pumps are required and usually no protection is provided against freezing. An electrical element is often inserted in the tank to provide back up heating.

Obviously, water heating systems appropriate for colder climates or used for commercial and industrial applications are of necessity more complicated, requiring electrical energy and control systems for the operation of circulating pumps and valves

The potential of solar heating for industrial process water application is currently being assessed in a number of demonstration projects which form part of the solar research and development programme of the Government of Canada.

1. **Load Profiles:** Water heating load profiles, as shown in **Figure 3.10.3.1-2** do not fluctuate seasonally and present a constant base throughout the year Hospitals, institutions, commercial and industrial buildings exhibit the same pattern, but can utilize hot water for reheat and service hot water. The domestic hot water load of a typical 138 m² bungalow represents up to 25% of the total heating requirement, whereas in a hospital it can account for 48% of the total annual energy consumption. Accurate heating load profiles are vital for the design of an effective solar energy system

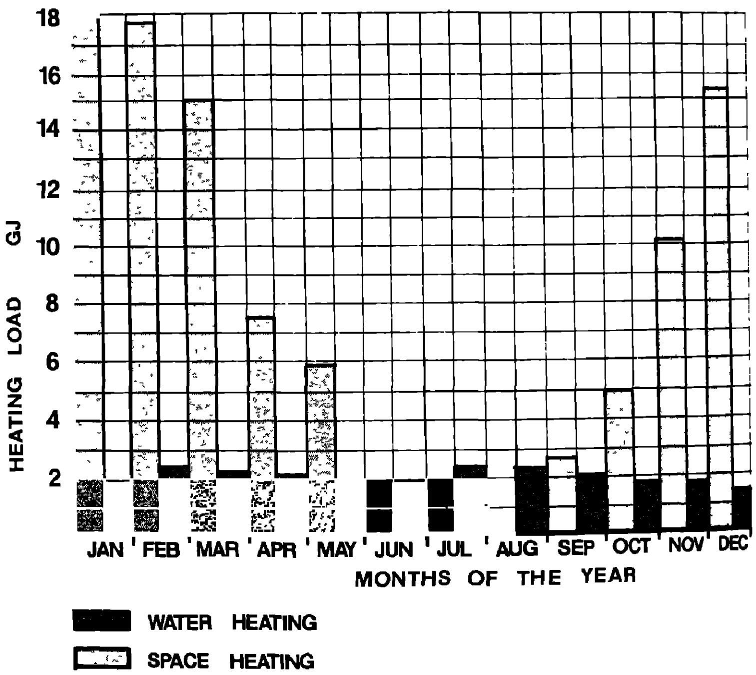


Figure 3.10.3.1-2
Space and water heating load for well insulated bungalow, 138 m², in Toronto

3.10.3.2 Space Heating Systems

A typical liquid space heating system utilizing a flat-plate collector is illustrated in **Figure 3.10.3.2-1** and may be described as follows

The liquid, flat-plate collector has a flat absorbing surface integrated with transfer fluid piping which, as described earlier, collects both direct and diffuse radiation. A steeper collection angle, for winter collection, distinguishes this assembly from the one described previously for year-round service water heating.

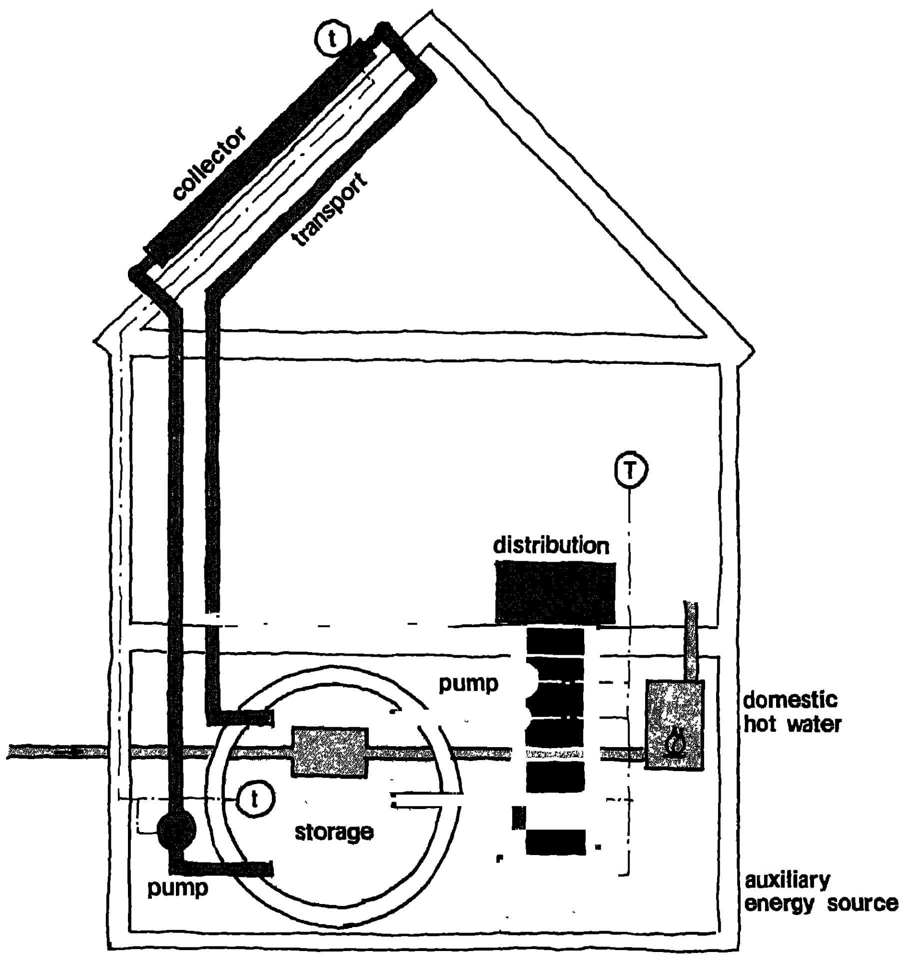


Figure 3 10 3 2-1
Liquid flat plate space heating system

Energy is removed from the collector by liquid flowing through conduits in the absorber plate. The liquid is pumped to storage where its heat is transferred and then returned to the collector to absorb more heat It is circulated through the collector only when the absorbing surface is hotter than storage.

Storage consists of either an insulated concrete or steel tank located near or beneath the building Between 50 L and 100 L of storage is required per square metre of collector area. Heat from the collector is either transferred to storage by a heat exchange coil passing through the storage tank or it flows directly into the tank

Freezing inside the collector panel is a problem that must be overcome. Because of the cost of anti-freeze solutions a closed loop heat exchanger is often provided inside the large storage tank, with a resulting efficiency drop and the added cost of the exchanger. A drain-down system which circulates the storage water directly into the collectors has the disadvantage of requiring larger pump capacity when compared with the closed loop.

The distribution system consists of a pump and pipes which deliver heated water to the occupied spaces. Theromostats control the water flow in a heat exchanger in the furnace bonnet or operation of fan coil units in each room or dwelling Liquid flat-plate collectors seldom deliver water above 65°C in winter operation For this reason, as mentioned earlier, most warm water distribution systems use air-water heat exchangers or enlarged convectors

Subject to the approval of codes, domestic hot water piping can be run through the central storage tank prior to passing through a conventional water heater Alternatively, a separate heat exchange loop can be used. This is particularly useful for summer months when space heating is not required but heat is being collected

3.10.4 Solar Air Systems

A typical residential air flat-plate system may be described as follows Figure 3.10.4-1 illustrates the basic principles

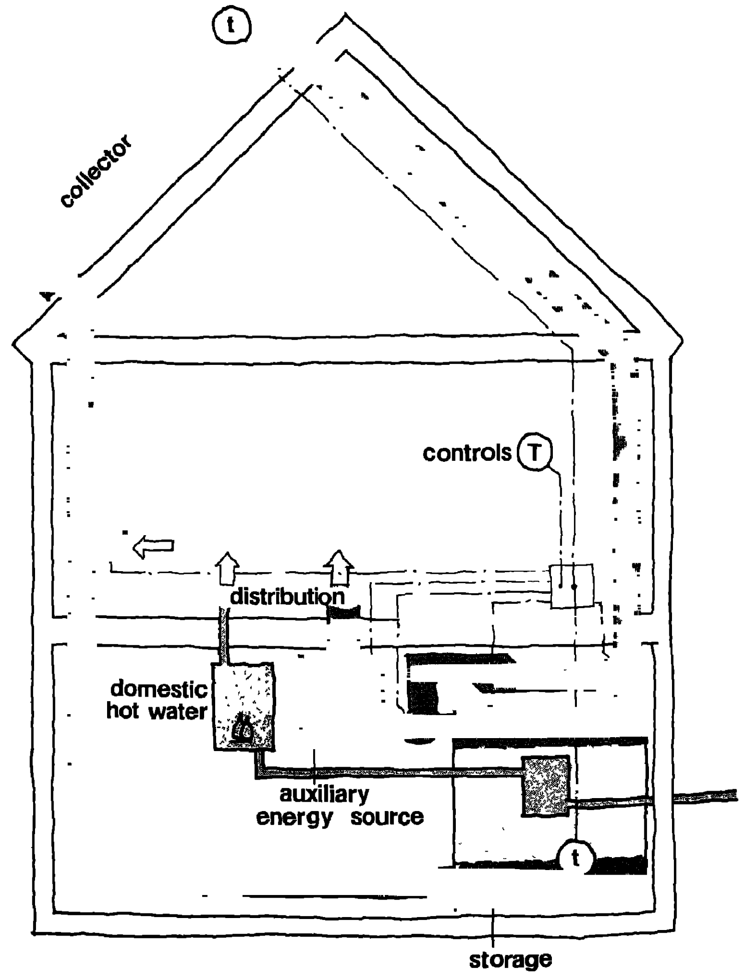


Figure 3 10 4-1
Air flat plate heating system

The air-cooled flat plate collector has an absorbing surface and collects both direct and diffuse radiation. Energy is removed from the collector by air flowing in ducts beneath the absorber plate. The system may be operated in four different modes:
—heating storage from collector
—heating house from collector
—heating house from storage
—heating house from auxiliary energy system

Typically, the four modes of operation are regulated by several sets of dampers. One set of dampers will direct air flow from the collector into storage or directly into the occupied spaces while another set will regulate air flow from storage to the occupied spaces. An energy boost may be supplied to the warm air by the auxiliary energy system before the air is distributed to the occupied space

Storage consists of rocks about 25 mm to 50 mm in diameter, contained in an insulated concrete bin in a basement area Approximately one quarter cubic metre of rocks is required per square metre of collector area A solar air system providing from 40% to 70% of the heating requirements of a 150 m^2 dwelling, well insulated, would have a collector area of 40 m^2 to 60 m^2

Because the temperatures in rock storage are typically highly stratified from inlet to outlet, the air flow providing heat to storage should be from top to bottom. This ensures that the temperature of air returning to the collector from the storage is as low as possible, thereby increasing collector efficiency. The air flow, when removing heat from storage, should be in the opposite direction to ensure that supply air to the rooms is as warm as possible

The hot air distributed to the rooms comes either directly from the collectors or from storage. Piping for the domestic hot water is run through the rock pile storage bin, or a separate heat exchange loop can be used As a result, the domestic hot water is preheated before passing through a conventional water heater, thus reducing the water heater's energy requirement.

3.10.5 Solar Cooling

During summer months, cooling equipment serving air-conditioning systems creates a large increase in the power required for building services This periodic need for additional power creates tremendous problems for the electrical utility companies, it lowers the annual utilization factor and increases the cost of electrical energy In some large urban areas, on occasion power demand has exceeded supply

The above problems together with the vulnerability of fuel supplies and the need to conserve non-renewable energy has created a new interest in utilization of solar energy for cooling.

A close examination of **Figure 3.10.5-1** shows that the values for average insolation and clear day insolation are very close during the warmer periods when most cooling is required, therefore, the application of solar energy for cooling seems to be most appropriate. The demand for cooling and the availability of solar energy also follow the same hourly profiles during the day.

The two main types of cooling demand are industrial and commercial refrigeration, required year round, and seasonal air condi-

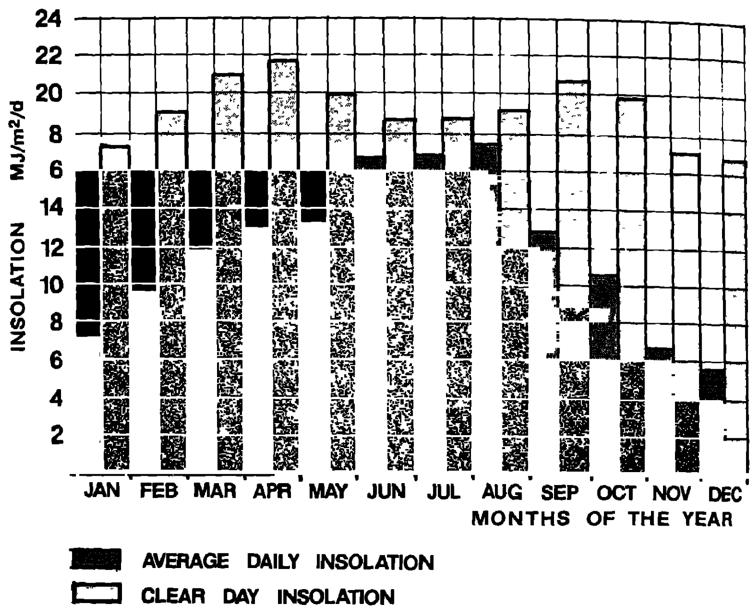


Figure 3 10 5-1
Insolation availability 45° slope

tioning Solar energy utilization for air conditioning is more viable due to the coincidence of available energy and cooling demand

Solar energy can be utilized for a number of air conditioning systems although, to date, none have been applied commercially in Canada

The three principal types are as follows·
—absorption
—vapour-compression
—augmented or assisted heat pump systems.

3.10.5.1 Absorption System

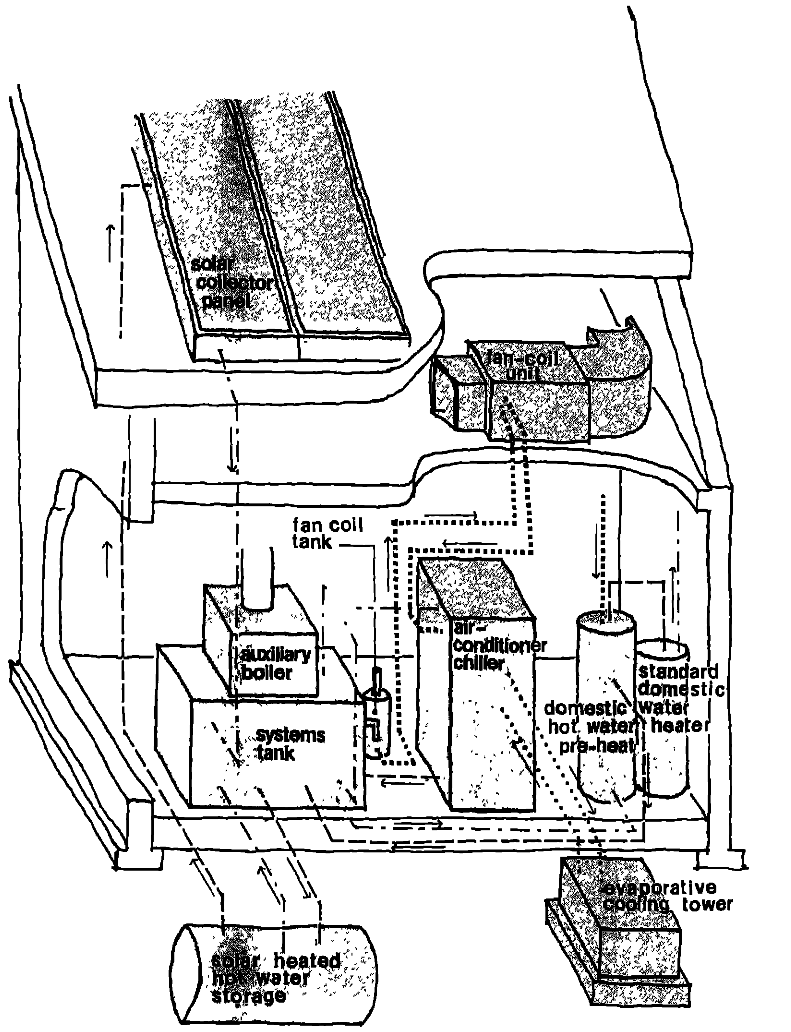
As described in **Section 3.8.7**, an absorption system does not require high grade energy to drive the compressor The required energy is compatible with that available from flat-plate collectors and consequently the need for auxiliary heating of water is minimized.

An absorption air-conditioning system functions on the principle that many substances can attract and hold large quantities of the vapours of other substances at a relatively low temperature The vapours are driven off when heat is added in the auxiliary boiler and the temperature is raised

Most widely marketed systems use lithium-bromide and water or an ammonia and water combination

A number of manufacturers provide absorption air-conditioning packaged units for heating and cooling. The system described below and shown in **Figure 3.10.5.1-1** is based on the Arkla Solaire System.

.1 **Typical System:** When solar energy is available, storage water flows to the collectors for heating, and then into the systems tank.



— · — · — · — SOLAR HEATED WATER
——————— RETURN WATER
·················· CHILLED WATER
·················· EVAPORATOR LOOP

Figure 3 10 5 1-1
Absorption air-conditioning system [15]

Water from the systems tank replaces the water taken from storage, thus completing the collection cycle This ensures that the hottest water is in the systems tank

.2 **Collection**: When solar energy ceases to be available, the collector pump stops, allowing the water in the collection circuit to drain back into the storage and systems tank. This provides freeze and over-temperature protection.

.3 **Cooling**: On demand for cooling, hot water from the system tank flows through the generator circuit of the absorption chiller

Using the energy obtained from the hot water, the chiller chills the water flowing through its evaporator circuit. This chilled water

continues to the fan-coil unit, where it cools the circulating building air The heat removed during the cooling mode is dissipated outdoors by the evaporative cooling tower.

The system can also provide hot water for space heating or domestic hot water as required.

3.10.5.2 Vapour Compression System

An alternative to utilization of solar cooling with an absorption system is to provide sufficient energy for solar engines which in turn will drive the water chillers In most experimental systems Rankine-cycle engines are used This is a highly advanced and expensive technology and is rarely used.

3.10.5.3 Augmented or Assisted Heat Pump Systems

Solar assisted heat pump systems are in the early stages of development. There are instances of their successful operation and they appear to offer considerable future potential.

Heat pumps are discussed in detail in Section 3.13.1.

3.11 District Heating

3.11.1 Introduction

District heating is usually understood to mean generation and distribution of heat 'in bulk' for a number of buildings within close proximity to each other. This heat is supplied by a central system fed from one or more plants. The heating fluid at the energy consumption point is generally used for space heating, cooling (through absorption units), domestic hot water heating and for other purposes.

District heating has the potential for making substantially improved use of our non-renewable energy resources through co-generation. Its high overall efficiency and flexibility in being able to generate energy from all conceivable fuels are attractive features compared to existing traditional approaches.

Furthermore, with increased support from governments and industry, district heating can become economically advantageous in the near future for both owners and users, as fossil fuels become depleted and their prices escalate.

The ultimate district heating system could satisfy the low temperature thermal energy requirements of an entire city.

3.11.1.1 Historical Review

District heating requires substantial capital investment for construction of a central heating plant and distribution system. In North America it has not been as successful as in Europe with the exception of a few isolated plants located in densely populated areas such as in New York. The economic climate for the widespread application of district heating has not been favourable until recent incentives created by the energy crisis.

The reasons for unacceptability in North America up to the present include the following:

—Local utility grids for gas and electricity distribution have been able to satisfy the needs of energy consumers conveniently and at a reasonable cost.

—Commercial and institutional buildings are being designed to meet energy conservation standards and therefore yield low energy demand and consumption. Consequently, it is very difficult to achieve a desirable load density for an economical district heating system.

—District distribution systems are capital intensive and, even for short distances, thermal losses can be in excess of 10%. However, central plant efficiencies are sufficiently higher than those of small individual furnaces that the overall energy efficiencies of district heating systems can be 20%-30% higher than those achieved in conventional heating plants.

—The independence of local energy utilities on this continent and competitiveness in the energy supply market have, in the past, made district heating in North America an economically unattractive proposition. In contrast, the European 'umbrella system' embraces different utilities and government provides subsidies and other incentives. However, energy shortages coupled with escalating costs of conventional fuels enhance the attraction and economic viability of district heating systems in North America and they are now being considered and even viewed favourably by government.

3.11 District Heating

3.11.1.2 Factors Influencing Selection

The following are the principal considerations which will determine whether or not a district heating system is appropriate for a particular application

.1 **Load**: The economic feasibility of a district heating system is markedly influenced by the load to be satisfied Concentrated loads lead to low cost distribution systems and steady year-round loads result in low operating costs and high thermal efficiencies A thermal density of 3 75 MW/ha is frequently indicated as a desirable load density for an economical distribution system Ideal loads are such as represented by hospitals and industries Residential dwellings, commercial and institutional buildings show a great variety in energy demand on a daily and yearly basis

.2 **Source of energy**: The choice of an energy source for central district heating plants depends on a number of variables such as
—plant location
—type of fuel available
—type of heating system
—environmental regulations

.3 **Air pollution regulations**: Incineration and boiler plants produce lethal and noxious gases in varying quantities However, the costly processes of emission control are best managed in large central installations The increasingly stringent anti-pollution requirements are met more efficiently and economically by district heating plants with accurate combustion and emission controls equipment than by numerous and smaller localized installations

4 **Financial considerations**: District heating systems are capital intensive as the cost of a complete generation plant plus its distribution system is far higher than the sum of individual plants for each building in a community

Therefore, a district heating system does not represent an attractive venture for private investors without tax-reducing incentives In the USA, under pressures of the energy crisis, incentives are now being proposed to enhance the construction of district heating systems utilizing co-generation

.5 **Local by-laws and ordinances**: Air pollution controls, construction and operating standards and legislation concerned with the sale of energy to others are often subject to stringent local and Federal regulations

All applicable regulations should be investigated thoroughly as they can affect the financial viability of a district heating plant

3.11.2 Types of District Heating Systems

There are two common types of district heating systems, steam and hot water The distribution medium in most North American systems is steam while European systems rely on hot water

3.11.2.1 Steam Systems

Most steam systems, such as the one in Detroit, U.S A utilize high pressure steam with no condensate return. This type of system requires minimal user equipment and can be applied to buildings equipped with hot water systems Moreover, steam can be used to generate cold in absorption air conditioning, industrial processes and sterilizing installations. Heat losses can be significant over long runs of distribution piping.

3.11 District Heating

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3.11.2.2 Hot Water Systems

Hot water systems operate at lower temperatures and require a feed and return main and pumping stations to maintain flow and pressure High rise buildings must be equipped with booster pumps so that the hot water supply can reach the upper levels. Heat losses are generally low

3.11.2.3 Description of District Heating Systems

District heating systems are divided into three major components generation, heat transportation, distribution networks and terminal utilization installations Figure 3.11.2.3-1.

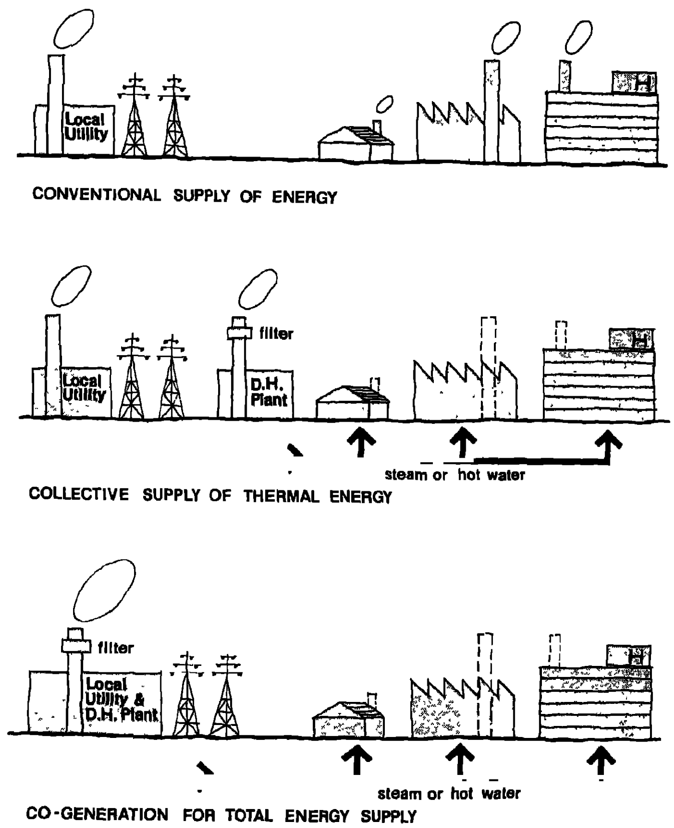


Figure 3.11 2 3-1
Development of district heating systems

.1 Heat generation plant: The heat generation plant of a district heating system is normally one of the following types:
—conventional boiler plant utilizing fossil fuels for generation of steam or hot water only
—combined heat and power generating station, better known as co-generating station; co-generation is the process of generating electricity and distribution of the heat that is otherwise lost in the process of electricity generation only
—refuse incineration plants where heat is extracted from the incineration of household and industrial refuse; co-generation is feasible in this type of plant
—combined schemes where heat from prime energy sources or co-generation is supplemented by surplus heat from industrial processes.

3.11 District Heating

.2 **Heat distribution**: The heat transportation and distribution network consists of underground pipes and related appurtenances The network is the most important part of the district heating scheme and represents by far the largest portion of capital investment Two types of network are commonly in use, **Figure 3.11.3-2**, they are

—traditional concrete ducts, constructed of prefabricated section or cast in-situ, to encase distribution pipes, pipes are traditionally manufactured of steel and insulated

—pre-insulated pipes for direct burial, consisting of the heating fluid carrier pipe surrounded with insulating material and protected on the outside by hard tubing

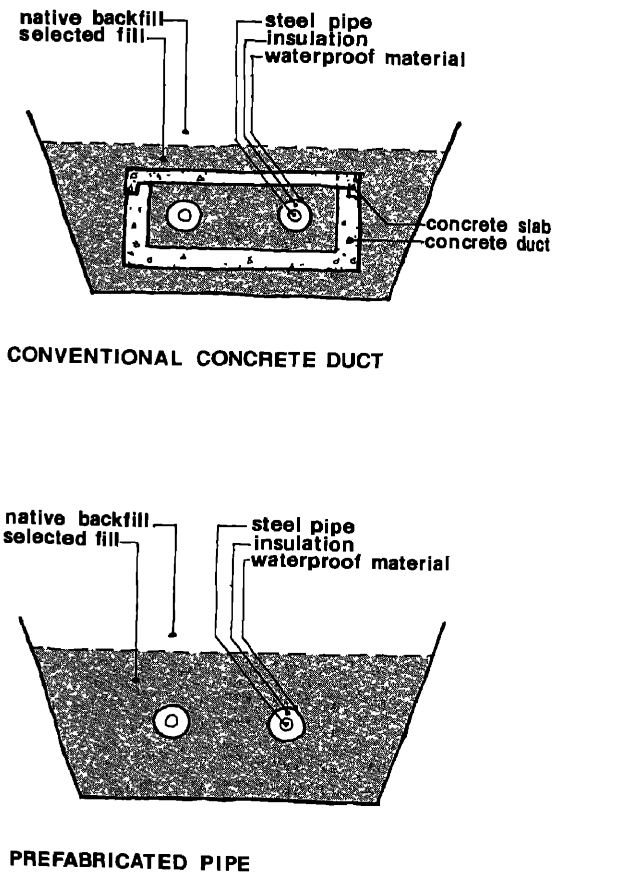


Figure 3 11 2 3-2
Types of distribution network

.3 **Terminal installations**: The terminal utilization installations basically consist of a heat exchanger, in lieu of a conventional boiler and a network of piping and heating elements

A major component at this terminal is the heat energy meter used for measuring energy consumption Two types of meter are presently available, namely, flow meters measuring the volume of the circulating medium through the heating installations and heat meters registering the amount of heat removed from the heating medium in thermal units.

3.11.3 Appraisal of District Heating Systems

3.11.3.1 Advantages

The following is a summary of the potential advantages of district heating systems

—Overall efficiency is higher than conventional heating plants by 20%-30%

—Co-generation of electricity and heat is possible This process more than doubles the plant efficiency and contributes to savings of up to 50% of prime energy resources Figure 3.11.2.3-3.

—Air pollution in a community can be reduced due to centralized source(s) of energy generation with greater control of pollutants

—Dependence on a single source of fuel is eliminated due to feasible use of available local fuels, low grade fuels and waste heat sources

—Fuel storage and handling is centralized thus reducing possibility of neighbourhood nuisance and pollution

—Expansion to serve existing and future communities under various conditions of loads and energy source availability is possible due to flexibility of system

—Mobile district heating plants can be brought into an area for immediate use as starter or satellite plants to meet the needs of any given situation

—Co-generation district heating plants can be linked into utility grids for use during peak periods or as additional standby power

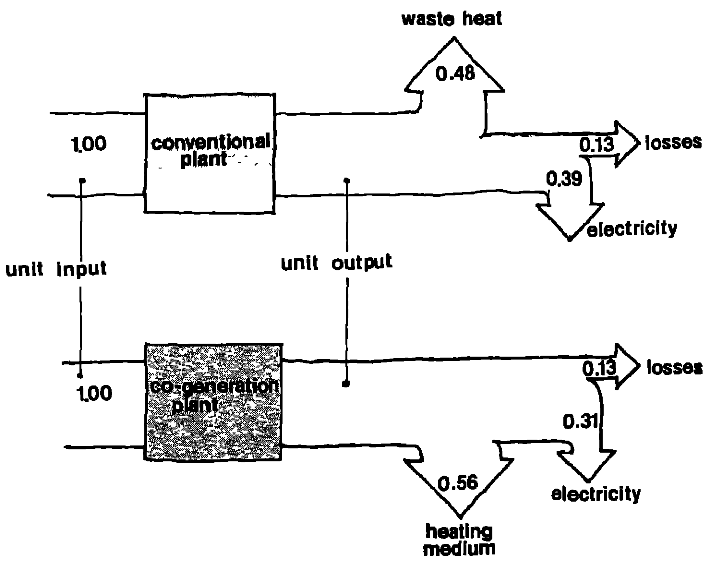


Figure 3.11 2 3-3
Comparative efficiencies, conventional and co-generation plants

3.11.3.2 Disadvantages

The following is a summary of the potential disadvantages of district heating systems

—Elaborate planning is required on local and national levels to secure optimum feasibility and compliance with national energy policies.

—High capital investment is needed mainly because of the underground transportation and distribution system costs
—Location of heat generating station(s) is critical viz a viz energy resources (availability, handling and storage) and community requirements for immediate and future energy needs
—Relatively high thermal load density is necessary to justify high capital costs
—Ownership aspects represent a major problem due to lack of legislation governing the operation of such schemes
—Underground transportation and distribution system must be designed to prevent damage from traffic loads, earth settlement and water penetration.
—Considerable heat is lost during transit from the generating plant to the energy user installations This loss ranges between 10% to 20% of the heat generated initially
—Terminal points require accurate and low cost energy consumption meters, these are not available

3.11.4 Management of District Heating Systems

As in the case of a large scale utility company, a district heating system requires competent administrative and technical personnel for its successful operation and maintenance

3.11.4.1 Annual Operating Costs

Included in the annual operating costs of a district heating system are the following
—energy production costs, which are basically the cost of fuel(s) and utilities
—transfer line costs, which depend on the distance between the generating plant and the main distribution lines
—distribution line costs, which represent the cost of heat distribution from the transfer lines to the terminal stations, these depend on the heat density of an area and the capacity of each energy user station in that area
—terminal station costs, which arise from the maintenance of metering devices and the connections from the network into the terminal station, generally, the terminal station installations are owned and maintained by the energy user
—administrative and operating costs, which represent a considerable amount of the total cost
—pumping costs (applicable to hot water plants only) which cover the cost of pumping hot water to overcome friction losses and maintain the designed pressure of the distribution network
—taxes, which cover all costs arising from taxes, storage and clearing charges

3.11.4.2 Annual Income

The annual income for district heating systems will be obtained from the following
—connection charges, which vary according to the type of connection and sizes of terminal installations
—tariff income, which consists of energy consumption charges, subscription, distribution and index charges

3.12 Wind Energy

3.12.1 Historical Background

The design of wind turbines has grown from centuries of practice of an ancient evolutionary artform to the beginnings of a modern aerospace-based technology

The commonly used term 'windmill' is, to some extent, a misnomer when applied in general to wind turbines. While it is true that many such turbines were indeed used to mill grains, the majority of these units in past history have been used to pump water. This was so in the early Chinese and Persian civilization, as it was in more recent times in Holland and the American west

The advent of heat engines in this century led to a displacement of wind turbines by fossil-fuel fired machines In few cases could wind turbines compete with the higher powers, convenience, and controlled outputs of the heat engines, and with a few notable exceptions, an hiatus in design innovation and their use occurred until the 'oil crisis' of 1973

In the first half of the twentieth century, mass production of wind turbines was limited to units under approximately five kilowatts rating. Typical of these were the reliable, slow-turning, fixed-pitch horizontal axis units found even today in large numbers in service in the U.S midwest

3.12.1.1 Classification

It is possible to classify wind turbines on a somewhat subjective size scale, based on rated output, such as

.1 **Small domestic or farm units.** These have ratings up to 10 kW and perhaps 12 kW The outstanding example from the past is the Jacobs two-bladed horizontal-axis type This design, long out of production, established an enviable reputation for reliability while at the same time incorporating in its design such modern attributes as controllable pitch blades, high blade-to-wind speed, excellent aerodynamics and low maintenance Several small firms are currently (1979) seeking out old Jacobs units, refurbishing them and offering these units for resale.

Vertical axis machines of the Darrieus type are relatively new on the available product line

.2 **Intermediate units.** The ratings of such models range up to approximately 200 kW These units serve two main applications, the first as energy converters for small community applications, and secondly (and currently of greater importance) as operational test or demonstration units for electrical power generation in conjunction with electric grid distribution networks In this latter respect they serve as pilot plant installations with a view to future installation of larger units and/or wind farms

Historically, the most successful installation in this category was the three-bladed, fixed pitch unit installed at Gedser, Denmark [1] It provided electrical energy for the Danish grid system between 1958 and 1968 and in 1977 the machine was restored and instrumented for test purposes.

In Canada the 230kW vertical axis unit (designed by NRC, constructured and installed for Quebec Hydro by DAF), and in the U S the two-bladed horizontal axis Mod O and OA units of 100kW and 200 kW respectively, are typical of the many designs currently under study.

3.12 Wind Energy

.3 **Large units, with ratings up to 2 MW.** For the first time in history large scale production of wind turbines (or WECs, from 'Wind Energy Converters') is currently planned This fact is of considerable significance, since previously all large machines were designed and built on a one-off basis The entry of major aerospace firms (such as Boeing and United Technologies in the U S , SAAB-SCANIA in Sweden, Dormier in Germany, etc) brings a background of advanced technology and resources previously not used on any significant continuing basis In addition, several governments and major utilities are beginning to take large-scale wind generation systems seriously

The Smith-Putnam unit[-] installed on Grandpa's Knob in Vermont U S A , in 1939 and rated at 1 25 MW was a worthy and notable forerunner of modern design

.4 **Experimental designs and extreme size units.** Little can be said here in respect to the innovative designs currently being investigated nor of the search for limiting unit size In the limited space available it is sufficient to state that these aspects of wind turbine technology show promise of future development for economical, practical units

3.12.2 Wind Energy and Available Power

Wind data are often misinterpreted and wind turbine ratings are even more misunderstood Since the wind is the direct source of energy insofar as WECs are concerned, it is axiomatic that a knowledge of the local wind regime is of utmost importance when considering the installation of a WEC, regardless of the size of the unit Wind data are all too often tested in an overly casual manner

In assessing the capability of wind turbines to extract energy from the atmosphere, the following limitations require immediate recognition

—Wind power is dilute The power available is in kinetic form, i e , power $\propto$ (air density) $\times$ (wind velocity)^3 $\times$ (area) In order to extract reasonably high powers, large turbine areas are required to compensate for the low density of air (1 21 kg/m^3) and relatively low velocities

—Wind power is intermitent and generally unpredictable Since the available power is a function of the cube of the wind velocity power fluctuations are even more dramatic than the velocity fluctuations The implications are obvious

(a) provision must be made to protect the machinery from over speeding and overstressing its components, in high winds
(b) provision must be made for energy storage during periods of calm or low winds (below cut-in speeds)
(c) installed ratings must be higher than the rating of alternative installations, e g , diesel engine powerplant, a utilization factor of 25% to 40% of rating is appropriate for most long term applications

—Wind power levels can vary greatly as a function of local topography Wind data are typically gathered from anemometers mounted ten metres above the ground at airports Since wind velocities can, and do, vary substantially with changes in local condition such as height, terrain contour, boundary layer conditions caused by trees, buildings, etc , local wind prospecting is most appropriate prior to a WEC installation

3.12.2.1 Power in the Wind

It is beyond the scope of this presentation to outline a complete energy analysis of wind turbines. This is amply covered in detail in various prime publications [3,4]

In summary, the equations of continuity, one-dimensional momentum theory, state (air as a perfect gas) and the energy balance of the First Law are applicable. Essentially the mass flux through the wind turbine is enclosed upstream and downstream. Flow follows the streamlines and does not cross the streamtube boundaries. An important point is that not all of the kinetic energy can be extracted from the wind which has a free stream (i.e., undisturbed) velocity of V_∞ well upstream of the turbine. If the velocity was reduced to zero downstream of the turbine (or indeed anywhere in the stream tube) the flow would obviously cease. The Betz limit gives the theoretical maximum extractable power in the wind, and is shown[5] to be

$$\dot{W} = 0.593\ (0.5 \rho A V_\infty^{\ 3})$$

where $\dot{W}$ = power (i.e., work rate)
α = air density
A = turbine disc area
V_∞ = undisturbed free-stream wind velocity

The turbine blades describe a disc (obviously in this example, for a horizontal axis machine), called an actuator disc, which has a pressure differential across it. This pressure differential is caused by the interaction of the air flow with the rotating blades, which extract part of the available energy from the air stream. In a real turbine some aerodynamic losses occur, which further reduce the magnitude of the extracted power. Generally speaking, in order to maximize efficiency, the larger the number of blades the slower the rotation rate for a given diameter, i.e. the ratio of tip speed to wind speed increases as fewer blades are utilized. The number of blades and rotational speeds substantially affects the capital cost of the machine as well as the aerodynamic efficiency, especially in the larger units.

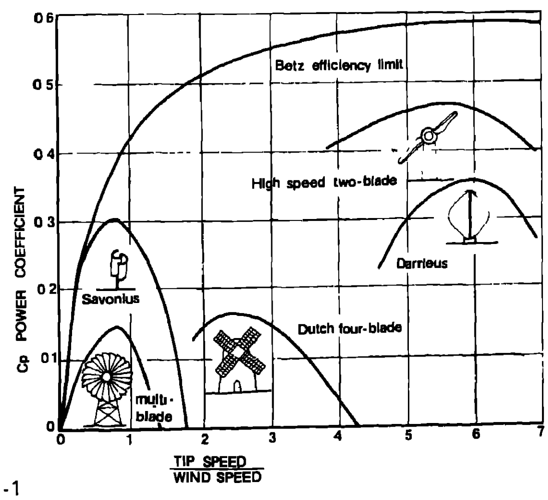


Figure 3.12.2.1-1
Performance characteristics of various wind energy converters

The power extraction results in a wind velocity reduction defined by an axial retardation factor, a. Analysis shows that when $a = ⅓$ then the theoretical Betz limit is achieved. If a is increased to ½, then the downstream velocity is reduced to zero and the air flow is stopped.

At the opposite limit, where $a = 0$, there is no momentum exchange between the air and the blades, hence no power is extracted

Unfortunately, in real WECs not only are losses also real, but the efficiency terminology is not yet fully standardized On the one hand the coefficient of performance is defined as the fraction of the undisturbed wind power that is extracted, thus

$$C_p \equiv \frac{\dot{W}}{0\ 5\rho A V_\alpha{}^3}$$

the Betz limit of wind power available that is extracted, thus

$$\eta \equiv \frac{\dot{W} \times 100\%}{0\ 593\ (0\ 5\rho A V_x{}^3)}$$

The relationship between the two terms, $\eta = \frac{C_p \times 100\%}{0\ 593}$, is often confused in the literature, and care should be taken that indeed the correct evaluator is used

3.12.3 Wind Prospecting and Site Evaluation

The importance of adequate wind prospecting is generally underestimated

3.12.3.1 Data Required

Three types of wind data are required The first type, which may be termed macrometeorological data, defines the hourly values of mean wind velocities over long periods, which leads to a site selection on the basis of annual energy-production estimates At very little expense, the meteorological data collected routinely from the Environment Canada weather stations are available in tabular form or in computer tape format These data are collected at a sensor height of ten meters above ground level, generally at airports The second type of data required are those related to the vertical wind gradient, and are generally not readily available The third type of data required are those related to the intensity and duration of extreme value winds (gusts and hurricanes)

.1 **Macrometeorological Data** The macrometeorological data allow one to crudely estimate the number of kilowatt hours that may be expected for a given WEC in a given location if the WEC performance specifications are known, Figure 3.12.3.1-1 If only the mean wind speed is known for a given location for a specific period, then in the absence of the probability density data, a Rayleigh distribution curve may be utilized For reasonable results, application of the Rayleigh distribution (a single parameter variation of the Weibull distribution) should be limited to conditions where the mean wind speed is four metres per second or higher [6,7] The meteorological based data will generally tend to underestimate the mean wind speed and hence the annual power output

.2 **Vertical Velocity Gradients.** The data-based estimate can be considerably improved if additional data on the vertical wind gradient is known for a specific site location. There can be significant increases in wind velocity with height The actual vertical velocity variation is a fairly complex function of terrain character, but can be

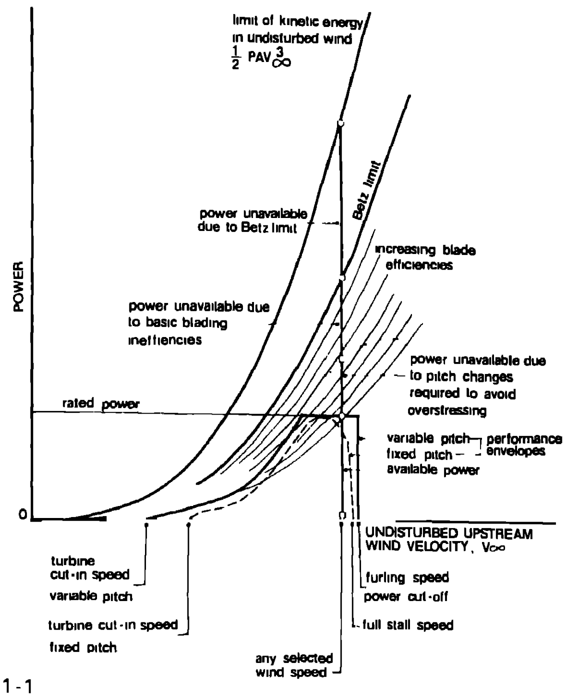


Figure 3 12 3 1-1
Available wind power as a function of wind velocity

generally described by a power function when the exponent, $1/\alpha$, is empirically based[8] Since WEC power output is a function of the velocity *cubed,* placing the turbine disc at an appropriate height where power output is compromised with tower construction costs, is well worth investigating Another aspect of the vertical gradient of the horizontal wind is the asymmetric loading of the turbine blades through the rotational cycle Tower 'shadow' (aerodynamic influence of the tower on the wind vectors relative to the blading) can couple with the vertical gradient to produce significantly high oscillatory stresses and subsequent vibrations For a WEC which should be able to function for a minimum of 20 years, possible fatigue failure should be carefully investigated Figure 3.12.3.1-2.

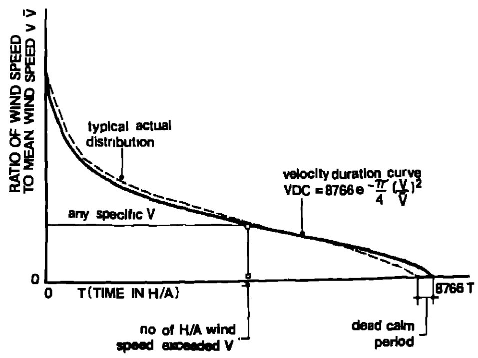


Figure 3.12 3 1-2
Typical velocity duration curve

.3 Extreme Value Winds. The intensity and duration of extreme value winds constitute the third type of wind data required Obviously one must expect hurricane force winds, on a probability basis,

during a 20 to 30 year projected life of a WEC These winds continue over a considerable time period, and provision must be made for the WEC survival by furling, braking or some other means During winter, lesser wind velocities can be just as dangerous to a WEC due to the increased air density and, more importantly, may deposit ice on the turbine blades Where gusts are concerned, a typical spectra would show[9,10] time constants ranging from approximately one second to about five minutes, with intensity peaking around one minute

3.12.3.2 Topographical Contours

The prime location for a WEC installation is at the top of a gently-sloped hill with a clear scope all around, Figure 3 12.3.2-1. The hill serves two purposes, it is an aerodynamic wind accelerator (in effect a single-sided nozzle) thereby significantly increasing the local wind velocity, and hence power availability, and secondly it provides increased height and a better velocity profile for the turbine The vertical compression of the streamlines close to the top of the hill tends to increase the local velocities more towards the bottom of the actuator disc than the top, thus compensating to some extent by thinning the boundary layer profile

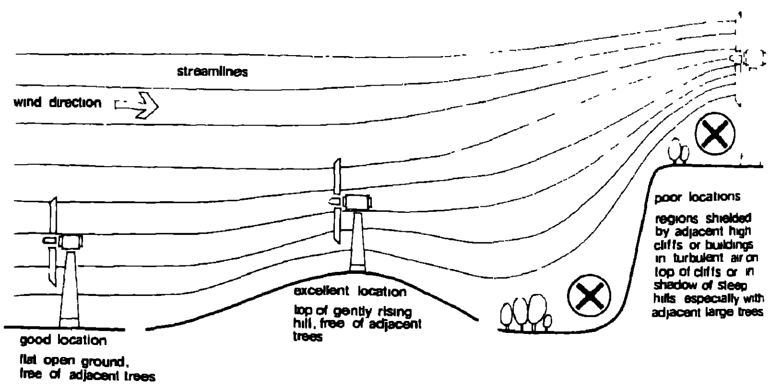


Figure 3 12 3 2-1
Site selection for wind energy converters

Failing the availability of such a hill, the next promising general location is on flat open ground free of adjacent obstructions such as trees, buildings, etc Regions definitely to be avoided are those dead air spaces such as are found at the bottom and tops of cliffs or very steep hills, particularly if they are wooded, Figure 3 12 3 2-1 The dead air spaces at the top of cliffs (or on the top of large buildings) are often underestimated

3.12.3.3 Instrumentation for Wind Prospecting

Regardless of the site tentatively selected, one should rent, buy or borrow an appropriate instrumentation mast complete with wind magnitude and direction sensors, data recorder and computational facilities including software Often subcontracting the wind prospecting chore is the best approach. It is important to examine the correlation of the site data with those data available from the nearest meteorological station. If reasonable correlations exist, then

the period of time for the site data collection can be substantially reduced In regions where icing of the blades is liable to be of significance, appropriate temperature and humidity sensors should be included in the instrumentation

3.12.4 Energy Storage and Management

Because power demand does not necessarily correspond to wind power availability in time and/or magnitude, any serious attempt to utilize wind energy as a primary source must be backed by some form of alternative energy There are several forms of energy storage available, each of which adds expense and inconvenience to a WEC installation

The end purpose of the WEC installation must be carefully considered in the choice of an energy storage system If the purpose of the installation is to obtain energy for heating or water pumping, generally a reserve energy source may be unnecessary In both cases some storage capability is inherent in the end use Water pumping and heating may then be accomplished by direct shaft drive and an electrical generator completely eliminated **Figure 3.12.4-1**. Thus if some mismatching of demand and supply can be tolerated, considerable expense can be eliminated for these applications

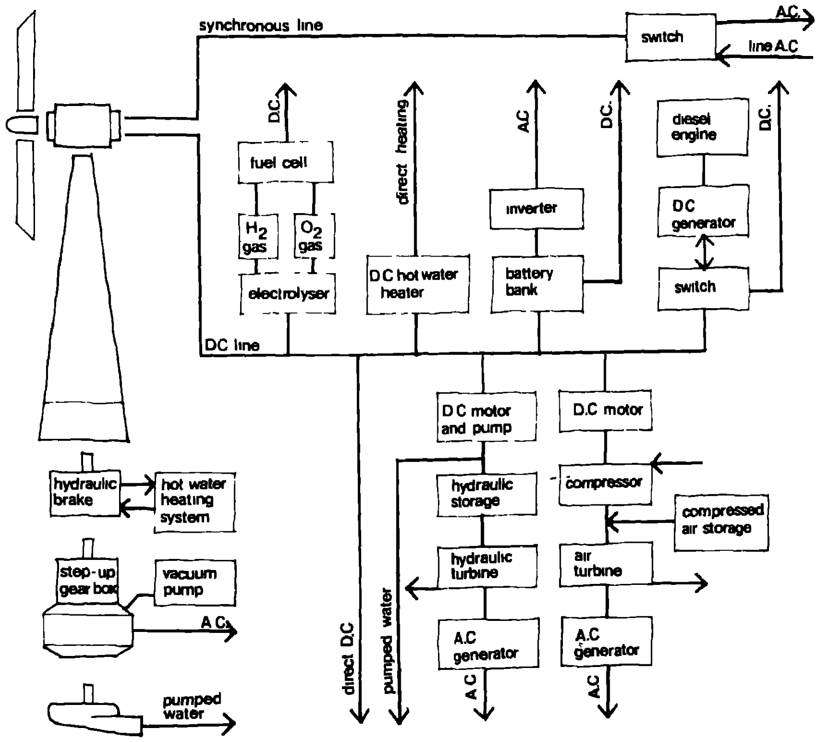


Figure 3 12 4-1
Possible wind energy conversion

3.12.4.1 Electrical Demand

Electrical energy is both the most versatile and most convenient form of energy for general use An accurate assessment of power requirements for various appliances is essential. An excellent set of tables for various household and farm appliances is available[11] showing typical power requirements (watts), usage rate (hours per

month) and energy consumed (kilowatt hours per month) Some of the major items from this source are listed in Table 3.12.4.1-T1.

POWER REQUIREMENTS			
Item	Watts	Hours per month	Kilowatt hours per month
Air conditioner	1300	100(?)	130(?)
Broiler	1500	8	12
Clothes dryer	4600	19	87
Clothes washer (automatic)	700	12	8
Electric frypan	1350	18	24
Portable heater	1500	30	45
Hotplate	1250	6	8
Refrigerator (standard)	300	200	60
Refrigerator (frost-free)	360	500	180
Deep fryer	1500	10	15
Dishwasher	1200	30	36
Electric baseboard heater	10000	160	1600
Electric iron	1200	12	14
Microwave oven	1000-1500	10	10 15
Electric range	12000	9	108
Toaster	1200	4	5
Water heater (180 L)	4500	87	392

Table 3 12 4 1-T1

Typical power requirements, household appliances[1]

Note that these are average figures and that the maximum power rating does not necessarily correspond to the maximum monthly energy consumption For example, an electric broiler requiring 1500 W power may only consume 144 (kW h)/a whereas a frost-free refrigerator rated at only 360 W power may consume 60 (kW h) a Obviously, a conservation-minded family judiciously can choose appropriate appliances and time their utilization to minimize energy storage backup The same reference also lists the power and energy requirements for major farm equipment

3.12.4.2 Energy Storage

The major forms of energy storage are as follows

.1 **Battery Storage**. The simplest and most direct means of electrical energy storage is by batteries They require relatively little maintenance, but for long life should be of the deep-discharge type The life of batteries depends not only on the design, but also on the quality of maintenance, cycling rate, load requirements, etc With care a set of good batteries can last well over a decade Considerable research effort is being spent on battery development for electrically driven vehicles and indications are that significantly improved battery designs will be available shortly Most lead-acid batteries require periodic topping-up with distilled water and adequate ventilation for the hydrogen gas generated during discharge They operate most efficiently at about 25°C , operation below this temperature tends to diminish performance, while operation at higher temperatures can seriously affect the battery life

.2 **Hydraulic Storage**. Another form of energy storage is limited in application to specific favourable circumstances This form is hydraulic storage, which depends on the availability of a suitable hydraulic reservoir One of the most promising applications for this arrangement is planned for the Wreck Cove hydro power site in Nova Scotia. Here the plan is to erect two intermediate sized WECs

on the Cape Breton plateau. The energy output from these units will then pump water from a lake approximately 300 m above sea level to the headwaters at the (approximately) 340 m level, from where it is passed through the existing hydraulic turbines to the sea level datum. This is a good concept for two primary reasons, one, there is a potential energy multiplier gain of approximately 340/40 = 8.5, and secondly, the hydro plant was designed as a peaking plant therefore extra water throughput can be readily accommodated by the existing hydraulic turbines

.3 **Compressed Air Storage.** Compressed air is a medium of energy storage that is often mentioned and discussed, but very seldom used This is probably due to several factors, including difficulty in matching components, cooling of the air in storage thus losing the temperature rise of adiabatic compression, difficulty in locating or fabricating a suitable storage container, and the generally high expense involved.

In intermediate and large size installations, where, coincidentally or through planning, there is a good wind regime in combination with a salt cavern or equivalent natural geological installation, the economics of compressed air storage may become attractive. It is extremely difficult to generalize on the advisability of attempting compressed air storage, and each prospective installation should be examined on its own merits, in economic and technological competition with other forms of energy storage.

.4 **Hydrogen Storage.** One of the most attractive forms of energy storage and utilization is the combination of electrolysis of water to form gaseous hydrogen and oxygen and the subsequent recombination of these gases, as required, by fuel cells

This system is attractive from several points of view. Storage tank size required is considerably less than that required for compressed air storage, since the latter depends on the pressure-volume work capability, while the recombination of hydrogen and oxygen is a chemical process releasing the very high specific calorific value of hydrogen Recombination by fuel cell, being a thermodynamic process rather than a thermal cycle (such as the diesel cycle), releases the system from the Second Law constraints of heat engines, and thus fuel cells can operate at conversion efficiencies of 85% or more An additional advantage is that the exhaust from the fuel cell is pure water—non polluting and recyclable. Further attributes of this scheme are its compatibility with the grand concept of the 'Hydrogen Economy'[13] and its adaptability to small or large scale WECs, on an individual or wind farm basis.

The spectre of hydrogen flammability has haunted the public since the flaming destruction of the Hindenburg The high specific calorific value of hydrogen, combined with its wide ignition range of temperatures and fuel-oxidizer ratios does require that gaseous hydrogen be treated with respect. However, its characteristics are well known and modern handling procedures combined with its low density and rapid dispersive properties do allow safe and consistent use of hydrogen. Recent developments in the storage of hydrogen by the use of metal hydrides[14] present exciting prospects for the immediate future. When cold, certain metal hydrides have the capability of absorbing hydrogen without the necessity for pressurization or cryogenic temperatures. When heated, hydrogen is released under readily controlled conditions.

This form of energy storage makes use of recently developed technology which should be well understood before being attempted for even small installations

.5 Flywheel Storage. This at an early stage of development By enclosing the flywheel in a vacuum chamber, utilizing gas or magnetic bearings and exotic materials and design techniques, high-technology organizations have produced experimental flywheel energy storage and conversion systems that exceed the energy density storage capabilities of batteries Whether or not these will become commercially feasible in the immediate future is open to speculation

3.12.4.3 Inverters

Recently, solid-state inverters have become available[15,16] which convert D C power to 60 Hz A C., match synchronously and can be connected to the electrical power grid This system requires the consent of the local power corporation, but if granted, has the advantage of supplying excess energy, when available, to the grid, for which a credit may be given In times of wind calm, energy may be drawn from the grid at regular rates Some D C energy storage is recommended for reliable operation This type of inverter makes use of modern solid state electronics but is available for relatively small power ranges only (typically 5 kV A) and is relatively expensive

3.12.4.4 Heating

If electrical energy is to be used for heating, D C is quite adequate Depending upon the utilization factor, the time-magnitude demand and the thermal inertia of the heated system, battery storage may be unnecessary If sufficient mass of heated water is used as an intermediary heat transfer medium then batteries do indeed become redundant In fact, an electrical generator is unnecessary if a step-up gearbox and water brake are used to degenerate the mechanical energy directly to thermal energy through fluid turbulence

3.12.4.5 Diesel-Electric Assist

It is possible to supplement periods of inadequate wind power by a completely separate internal combustion engine-generator However this solution, although reasonably convenient, does require the use of fossil fuels and thus to some extent circumvents the prime purpose of installing a wind turbine in the first place

There should be little difficulty in matching the two sources to the load for D C output. Feedback throttle control of diesel engines is routine, and proper selection of the WEC and diesel powered generators should not be excessively difficult if the load characteristics are known The possibility also exists of placing dual generators on the diesel engine and simultaneously producing D C and 60 Hz A C outputs

3.12.4.6 Synchronous Generation

For medium and large WECs connected to electrical grids an attractive conversion system is that utilizing a synchronous generator tied in electrically to the electrical grid through a two way distribution system. Metering can also be on a two way basis, if the

power corporation is willing. Controllable pitch blades on the wind turbine are definite assets here, but fixed pitch turbines can also be used if designed and matched with care, and if suitable overspeed breaking or furling is included

This system is presently being used by the Quebec Hydro Darrieus WEC installation in the Magdalen Islands rated at 230 kW, and by the U S department of Energy in installations up to 2 5 MW in size

3.12.4.7 Direct Mechanical Power Take-offs

Alternatives to electrical power generation by wind turbines include several variations of direct mechanical drives to water pumps, grain milling apparatus and water brakes for heating purposes The first two applications have been used for centuries and do not require high level technology in their design or application The heating application is more modern in concept and is particularly applicable since, typically, wind power is greater in winter than in summer

3.12.5 Economic Evaluation and Wind Turbine Selection

3.12.5.1 General

Although the 'fuel' powering wind turbines is free, the low density of air and the variance in wind strength demand a large structure relative to power output and, in most cases, an energy storage sub-system Thus the capital cost per kilowatt hour production capability is rather high relative to some more conventional power plants, e g gasoline powered electric generators

Size is an important factor in the economics of WECs. Although small wind turbine units have been produced in reasonably large numbers in the past, so far large scale units have not been mass produced However, an interesting new factor has been introduced into the wind turbine scene The advanced technology of the aero-space industry has been brought to bear on their design. Several aero-space firms in the U.S and Europe (e g. Lockheed, Boeing, United Technologies, SAAB) are producing prototype machines in the megawatt class and planning production of these in the hundreds of units

Government and private utilities in many countries are showing equivalent interest in wind turbines Test sites for large units are being established on an individual basis, while the smaller wind turbines can be tested and compared at multiple-unit test sites being set up for this purpose.

3.12.5.2 Cost of Energy

With fossil fuel costs and interest rates rapidly escalating, a direct economic comparison of WECs with more conventional plants becomes difficult, especially if one tends to generalize. Regardless of the type of powerplant, the cost of energy can be represented by the simple relationship.

$$\text{Cost of Energy} = \text{CoE} = \frac{100/(C \times R) + F + M}{E} = ¢/\text{kW} \cdot \text{h}$$

where C = total capital powerplant cost, including auxiliaries required, \$
R = annual fixed charge interest rate, \$
F = annual fuel cost, \$
M = annual maintenance cost, \$
E = annual energy production, kW h

.1 **Capital Cost Breakdown.** For most wind turbine units, especially the larger ones, the three most important single capital components are the rotor, the drive-train and generator unit, and the tower Estimates for the one hundredth production unit of the MOD-2 machine (2 5 MW) are given in **Table 3.12.5.2-T$_1$**

CAPITAL COSTING, COMPONENTS		
Unit	Cost (1977 \$)	Cost percentage of total
Rotor	329,000	21 1
Drive Train	379,000	24 3
Tower	271,000	17 4
Site Preparation and erection	299,000	19 2
Nacelle, spares, etc	283,000	18 0
Total Initial Cost	\$1,561,000	100 0

Table 3 12 5 2-T$_1$
Estimated cost for one hundredth production unit of 2 5 MW wind turbine[15]

Not included in the above estimated costs are commissioning fees (10% of total initial cost) and an annual maintenance cost of \$15,000 Since generation in this unit is by synchronous machine, to be connected directly to the electrical grid, storage costs do not enter. The above estimates are considerably below prototype costs

3.12.5.3 Wind Turbine Selection

For reasons previously stated discussion here is limited to small sized WECs

.1 **Suitability.** Small sized WECs vary greatly in costs They also vary greatly in quality and wind-speed ratings In choosing such a unit great care must be taken to select one on the basis of reliability, compatibility of unit to local wind conditions, rating suitability and safety features in extreme winds and icing conditions. One should insist on actual test data along with guaranteed costs

.2 **Configuration.** Small sized wind turbines come in a variety of configurations.[16] With the reasonably small rotor diameters involved the stresses sustained by the blades are not near material limits, as with large sized WECs Consequently horizontal-axis turbines have two, three, four and as many as thirty-six blades Generally only those with three or two blades have controlable pitch rotors With very few exceptions, small WECs have upwind rotors (i.e. rotors upwind of the towers) and are oriented into the wind by fixed wind vanes.

.3 **Available units.** The standard of small sized WECs is the venerable Jacobs Wind Electric unit[17,18] which has set the tradition of efficient design and quality workmanship together with reliable performance. Although no longer manufactured, old Jacobs

units sell at premium price today The philosophy and standards implicitly defined by the Jacobs units have been the basis of more modern units, one such has a rotor diameter of 3.66 m, a cut-in wind speed of approximately 2 7 m/s and develops rated output at approximately 11 2 m/s. The cost in U S. currency in mid 1979 was slightly under $3000 A larger unit has a rotor diameter of 4.27 m and a cut-in wind speed of 3 6 m/s Mid 1979 cost in U S currency was slightly under $5500

A comparison of these two units indicates that the larger has a higher coefficient of performance and lower cost per kilowatt than the smaller unit This is reasonable and serves to emphasize that scaling effects do exist, but more importantly that a cursory evaluation of skeleton specifications is not an adequate basis for selection. Actual test data should always be related to wind availability data for any specific application(19)

In addition to the horizontal axis types, both fixed and variable pitch, several vertical axis types are also available(16,17) They are primarily of the Darrieus type with fixed pitch blades in a troposkien configuration (giving spanwise tensile stress only), as pioneered by the National Research Council(20) Some ingenious and promising variable pitch vertical axis designs are in the design, prototype or limited production stage

3.13 Heat Recovery

3.13.1 Heat Pumps

A heat pump is a device that can be used for heating buildings in winter and cooling in summer. Heat pumps can conserve energy resources for heating by producing as much as 2.5 kW of heating for each kW of power input. This is done by extracting heat from an outdoor source such as air, water, earth, solar radiation and utilizing it indoors. Excess heat from internal cores of large buildings can also be recovered and used, in which case the useful heat can be as high as 5 kW for each kW of power input. During cooling operation the heat removed from a building is pumped outdoors or recovered in a thermal storage system.

Larger heat pump systems generally conserve more energy, particularly if the modular design is used.

The use of heat pumps driven by reciprocating engines, turbines or other on-site prime movers offers the opportunity to reclaim waste heat from exhaust combustion gases and jacket cooling systems to attain a higher efficiency than electrically driven heat pumps or direct fired combustion equipment.

3.13.1.1 Theory

The heat pump is a thermodynamic machine which employs the vapour-compression refrigeration cycle to remove heat from a heat **source** at a lower temperature and transfers it to a heat **sink** at a higher temperature.

The heat pump employs the same basic principle as a household refrigerator, extracting heat from the inside of the box and transferring it to the surrounding air. The only basic difference between a refrigerator and a heat pump is that the heat pump is arranged and controlled so that it can move heat in either direction. In other words a heat pump both heats and cools depending on the requirements. The principles of operation of any refrigeration cycle are based on five physical laws:

- —Heat exists in all substances down to absolute zero (−273°C). It is important to keep in mind that heat and cold are not two separate values—cold is merely the relative absence of heat.
- —Heat always flows from a higher temperature to a lower temperature under natural conditions.
- —All gases become warmer when compressed.
- —Most materials can be changed from a liquid to a gaseous state by the addition of heat (boiling) or from a gaseous to a liquid state by removal of heat (condensing). The temperature at which a material changes from a liquid to a gas or from a gas to a liquid depends on the pressure on it.

Heat pumps are basically refrigeration machines and thus consist of the same components, namely:

- —two heat exchangers: the evaporator and the condenser
- —expansion valve and electrically driven compressor
- —interconnecting piping filled with refrigerant liquid

Figure 3.13.1.1-1 shows the processes involved in heat pump cycles for both heating and cooling.

3.13.1.2 Coefficient of Performance

The operating efficiency of a heat pump is called its Coefficient of Performance, usually abbreviated COP. It is defined on the heating cycle as the ratio of useful heat obtained from the condenser to the heat equivalent of the electrical input to the system. While fuel

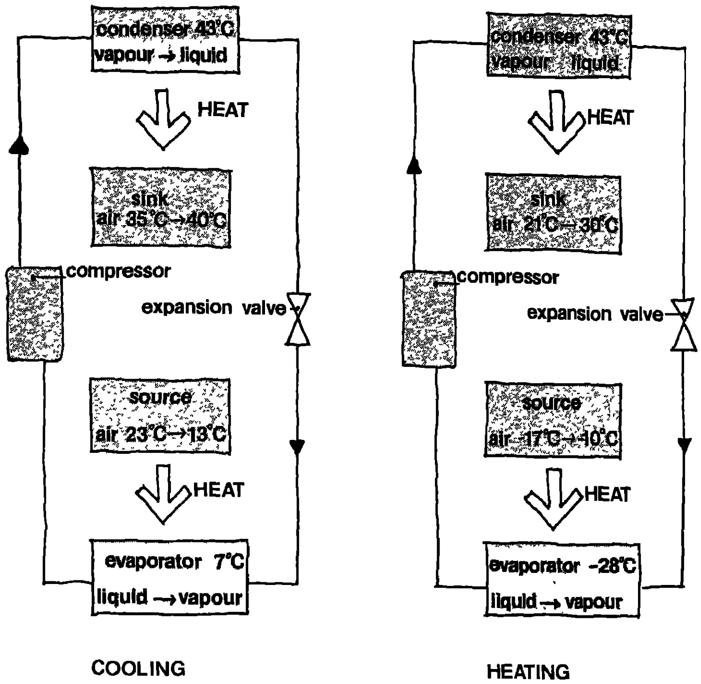


Figure 3 13 1 1-1
Air source heat pump cycles

heating systems have an efficiency of less than 100%, at the point of utilization the heat pump has an 'efficiency' or COP greater than 100% This is because the electric energy is used primarily to transfer or pump the heat from a low temperature source to the high temperature condensing medium, usually conditioned air.

As the evaporator temperature in any refrigeration machine goes down, the efficiency decreases Therefore, an air source heat pump has a decreasing efficiency, or COP, when the outdoor temperature goes down as indicated in **Figure 3.13.1.2-1**. Other major factors which determine the COP are the compressor, the refrigerant, the system design and the system loading The COP of most commercially available air source heat pumps varies from about 3.2 to 2 6 at 4°C, to a range of 2 6 to 1.9 at −12°C

Internal source heat pumps as used in buildings or heat pumps using well water or industrial processes have heat sources of relatively constant temperature, thus their COPs are constant and independent of outdoor temperature.

3.13.1.3 Heat Pump Types

Heat pumps are generally classified according to
—type of distribution
—method of reversing the machine between heating and cooling
—heat source and heat sink

.1 **Type of distribution**: Domestic window air conditioning units and domestic refrigerators use direct expansion distribution systems. In these systems the evaporator and condenser are in direct contact with the air being conditioned.

3.13 Heat Recovery

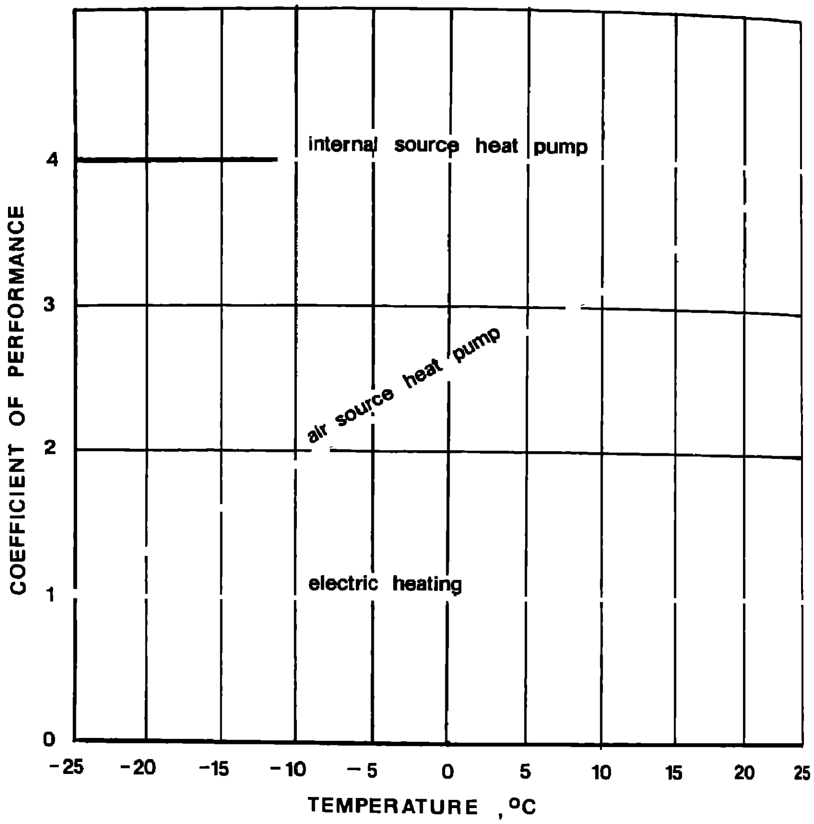


Figure 3.13.1.2-1
Simplified Coefficient of Performance curves

In large commercial air conditioning systems there is no direct contact between the air being conditioned and the heat pump Chilled water and heating water distribution systems are used to transfer heat to and from the evaporator and condenser, these systems are called indirect expansion systems

.2 **Method of reversing the machine between heating and cooling** Two principal methods of reversing heat pump operation are used The first involves rerouting the distribution system without modifying the refrigeration cycle The second method involves reversing the refrigerant flow so that the evaporator and condenser change functions, in this case the distribution system is not modified

.3 **Heat source and heat sink:** Heat pumps have been used with a wide variety of heat sources and sinks. The following configurations have been developed during the last few years and are gaining increasing acceptance.

—Air Source:

Air is most commonly used It is universally available in inexhaustible quantities. Also, air source systems generally require less maintenance. However, heating capacity drops and periodic defrosting is required as the outside temperature drops. The effect of these conditions can be minimized by careful heat loss calculations and proper system design and control Figures 3.13.1.3-1, 2, 3.

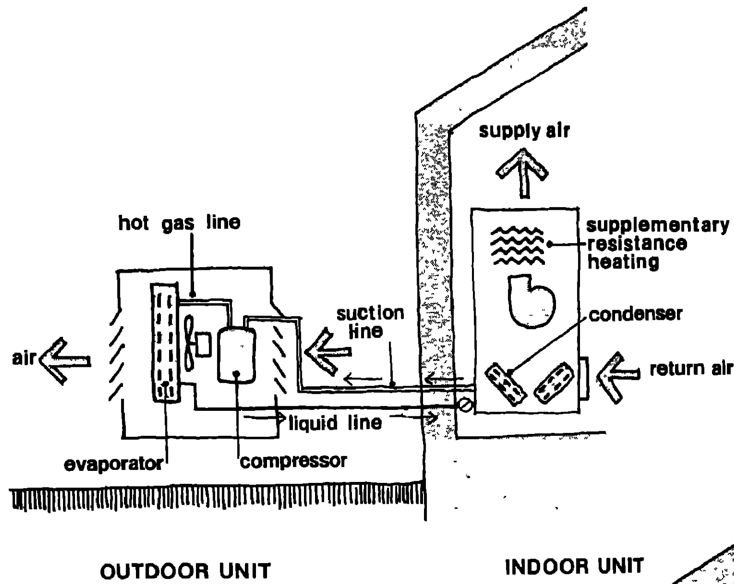


Figure 3 13 1 3-1
All electric heat pump system [1]

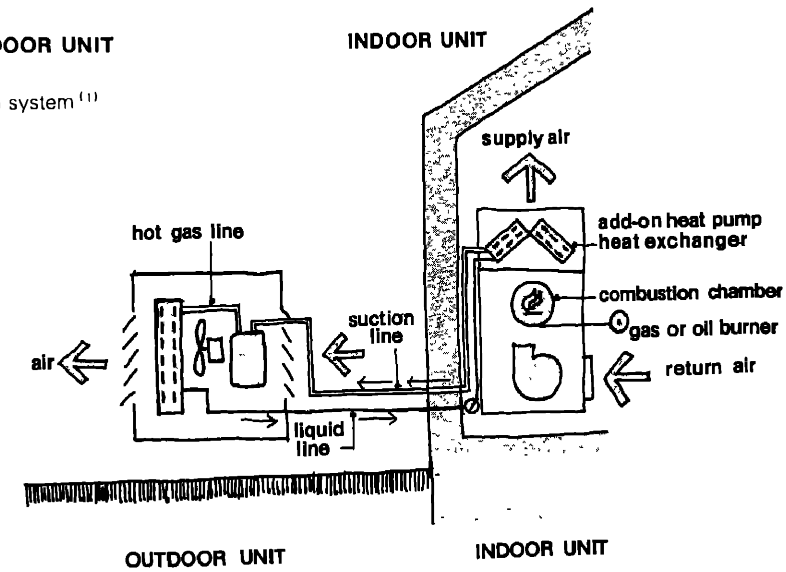


Figure 3 13.1 3-2
Add on heat pump system [2]

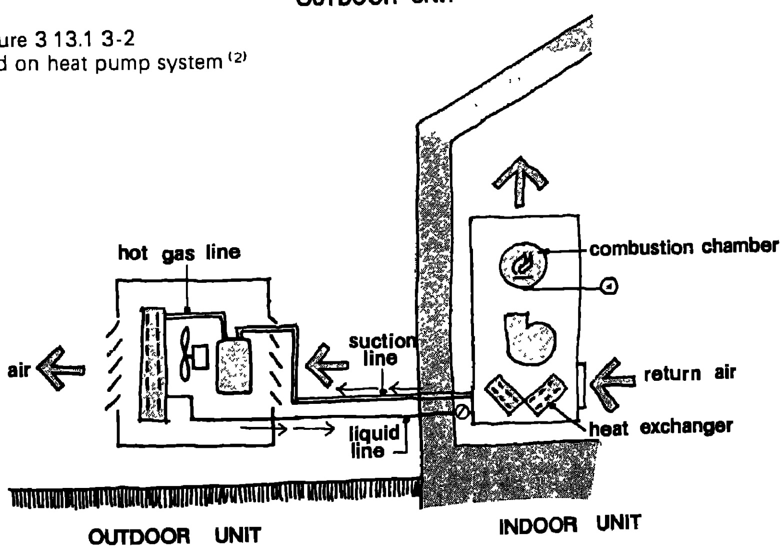


Figure 3.13 1 3-3
Hybrid heat pump system.[3]

—Water Source:
The water source heat pump draws heat from a well, river, or perhaps a lake Where the water is available in a dependable quantity, of good (non-corrosive and non-scaling) quality, and at a favourable temperature throughout the year, it is the best possible natural source of heat Well water is usually the best of the several natural water sources The temperature is fairly constant, usually above 10°C, which provides a good balance between heating and cooling capacities

—Earth Source:
Research efforts in the 1950's revealed that except for some relatively small experimental installations, ground source systems are not economical Extensive buried piping systems and ground area requirements make the original cost prohibitive Technical problems such as corrosion and local freezing have also been encountered These difficulties and the uncertainty in predicting performance have precluded the use of heat pumps of this type

—Industrial Process Source:
Heat available from industrial loads such as air compressor cooling water, welders, and electronic equipment, and other processing equipment makes an ideal constant quality heat source at a relatively high temperature level Any waste heat from a plant should be considered as a good source of heat Heat salvaged from ventilating air may be just as suitable as that from cooling water

—Water Loop:
The water loop of hydronic heat pump systems consists of a series of water-to-air, reverse cycle air-conditioning units, connected to a two pipe, closed loop water circuit Figure 3.13.1.3-4. The loop water temperature is maintained througho...

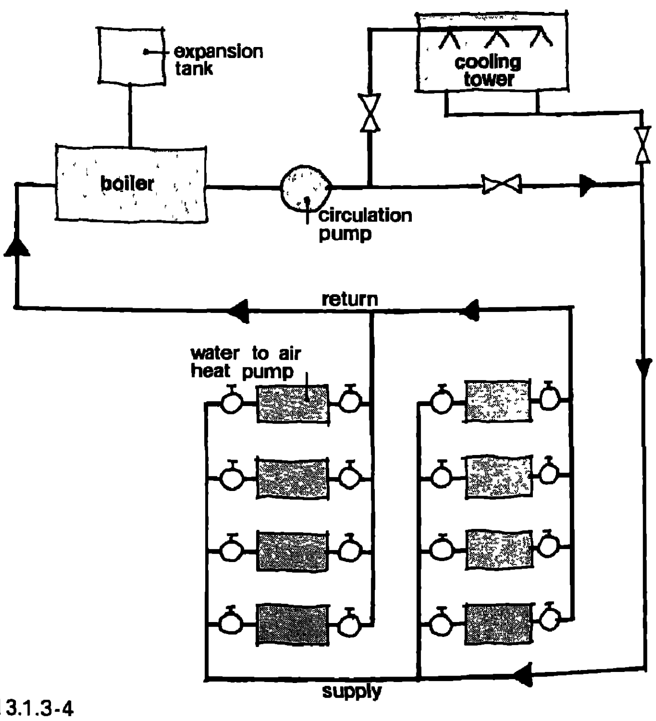


Figure 3.13.1.3-4
Water loop heat pump system [4]

the year between 16°C to 32°C which acts as both 'source' and 'sink' for the individual heat pump units On demand for heating, the heat pump will absorb heat from the loop water or on demand for cooling a space, the heat pump will reject heat to the loop circuit Whenever the loop water temperature drops to the low end of the range during winter, a supplemental central heat source (boiler) adds heat to the system Whenever the loop water temperature rises to the high end of the range during summer, a heat rejector (evaporative cooler) dissipates excess heat to the atmosphere.

Energy is conserved by pumping heat from warm to cold spaces whenever they occur simultaneously within the building

—Internal Source:

The most advanced and successful type of heat pump developed during the last decade is the internal source heat pump as applied to commercial, institutional and industrial buildings The concept is not new and has undergone a number of evolutionary changes

In most modern buildings sufficient heat is generated from lights, equipment and people within the building during occupied periods to balance heat losses This internally generated heat can be redirected toward the building envelope and used to heat the ventilation air A conventional air conditioning system requires operation of independent sources for heating and cooling

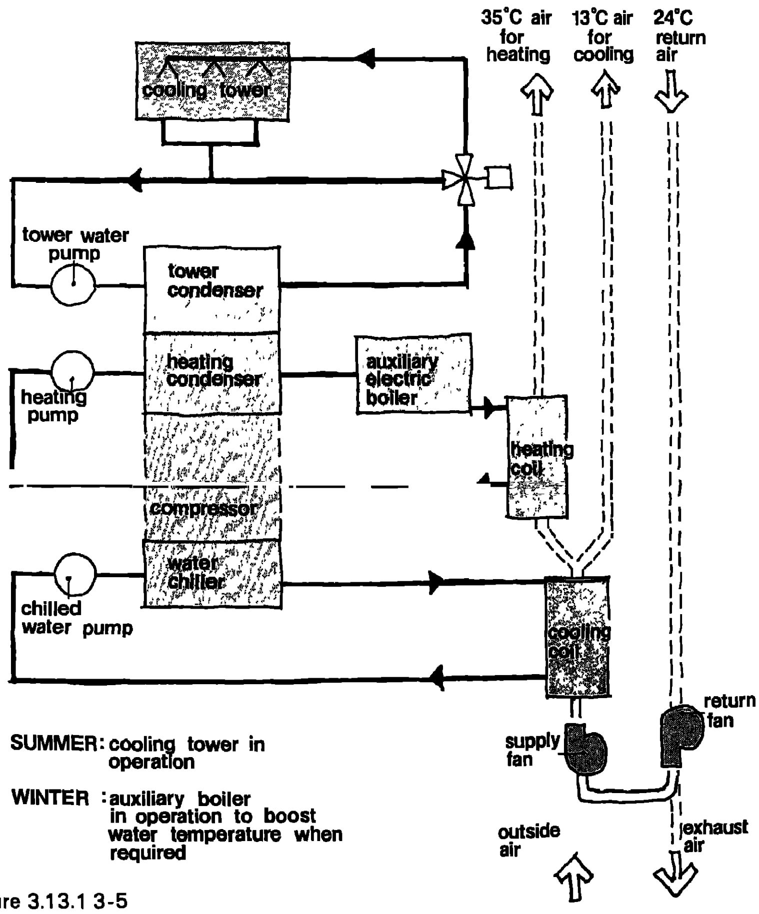


Figure 3.13.1 3-5
Internal source heat pump system.

throughout the year Thus heat and cold producing equipment is at odds, wasting an unknown amount of energy all year long

The internal heat pump system's centrifugal refrigeration compressor moves and redistributes all heat generated within the building toward locations where the heat is needed and rejects only excess heat to the outdoors, as indicated in Figure 3.13 1 3-5 This excess heat may be stored in thermal tanks during occupied periods, to be used for heating during nights and weekends

3.13.1.4 Heat Pumps and Solar Energy Systems

Heat pumps are often used to enhance solar system performance A heat pump is installed between the heat storage system and heat distribution system

In typical systems the heat pump is used when the storage temperature is low to extract low temperature heat and to deliver this at useful temperatures to the distribution system. When the storage is at sufficiently high temperatures the heat pump is bypassed This mode of operation increases solar system effectiveness in two ways

—The temperature range of operation of the storage medium is increased thus decreasing the amount of storage needed

—The average operating temperature of the storage and solar collectors is lowered Solar collectors are more efficient at lower operating temperatures, this increases the amount of solar energy collected and reduces heat loss from the storage

In systems using air as a heat transfer fluid, and pebbles for heat storage, an air to air heat pump is usually used Air withdrawn from the pebble storage is blown across the heat pump evaporator coils and is heated for distribution by being blown across the condenser coils

The same principle is applied to systems using water heat transfer systems and storage A heat exchanger arrangement is used to transfer heat from the storage to the evaporator and from the condenser to the hot water distribution system

In solar systems using phase change materials for heat storage, the temperature at which the phase change occurs determines the operating temperature of the storage and the temperature at which heat can be supplied In this case a heat pump may be needed if higher end use temperatures are required

3.13.2 Heat Recovery from Luminaries

In commercial buildings, electric lighting is probably the largest single contributor to internal heat load, and, for a number of years engineers have been designing systems that siphon off a large portion of this heat before it enters occupied spaces This reduces cooling load in the rooms, which means less fan energy is required If most of the return air is reused (the balance being ventilation air) there is little reduction in refrigeration tonnage required On the other hand, when the chiller system is designed for heat recovery the heat extracted from return air can serve as a source of low-grade heat in cold weather to provide warmth for perimeter spaces

3.13.2.1 Air Handling Luminaire Systems

Wherever illumination levels exceed 750 lx, consideration should be given to air handling luminaire systems. All these systems reduce the amount of sensible heat entering the space as well as the amount of heated air which must circulate in the air conditioning system, thereby reducing energy consumption.

The wet 'troffer' type air handling luminaire system saves an even greater amount of energy as well as some capital costs of the air conditioning system since it results in a smaller refrigeration plant, as well as smaller air handling units and ducts. Both systems, of course, reduce the quantity of sheet metal ductwork that is required

3.13.2.2 Air-Return Plenum System

Many office buildings today use the ceiling space as a return-air plenum The return air is drawn into the plenum through the luminaires, and much of the lighting heat goes into the plenum space This results in a reduction in cooling load as the occupants of a particular floor are exposed to half or less of the heat from the lights

When air is pulled through luminaires the extraction of heat can result in an increase in light output of 15% or more The typical flow rate is approximately 0 3 L/s The maximum desirable rate being 0 7 L/s as higher rates could result in a 'whistling' noise Some manufacturers report as much as 75% removal of lighting heat at maximum flow rates

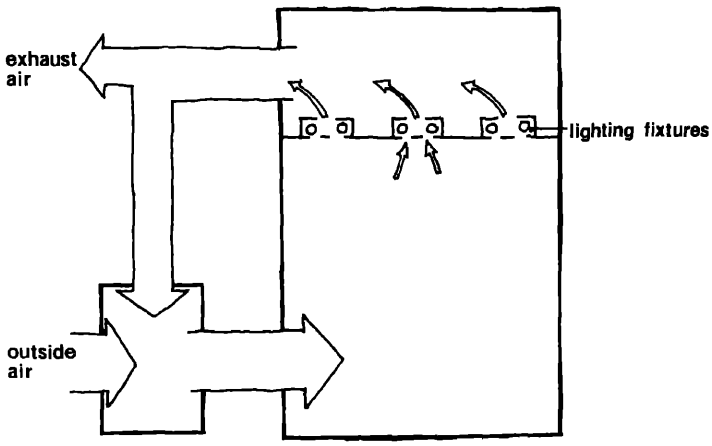


Figure 3 13 2 2-1
Total return system [5]

3.13.3 Exhaust Heat Recovery

The concept of recovering heat released from buildings has only recently become a serious consideration in applications other than industrial processes. A wide variety of technologies and equipment is available to recover heat from ventilation air and hot waste liquids in a broad temperature range.

Consultation with manufacturers and a calculation of detailed cost analysis is recommended before planning a heat recovery system The following are examples of the most efficient systems presently available.

3.13 Heat Recovery

3.13.3.1 Heat Recovery from Ventilation Systems

A typical heating/ventilation system shown in **Figure 3.13.3.1-1** brings in cold air (−23°C on the coldest day), heats it to 21°C and exhausts it at 21°C A system in Toronto circulating 472 L/s requires a 25.3kW heater consuming 53 130 kW h annually to meet this heating load

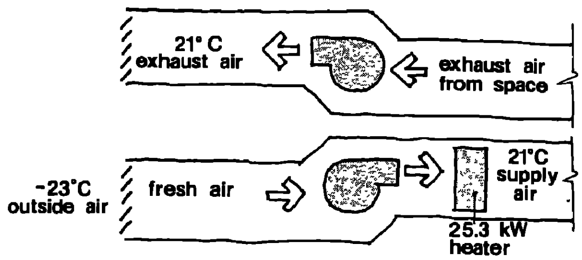


Figure 3 13 3 1-1
Typical ventilation system

The same ventilation system with a heat recovery device is shown in **Figure 3.13.3.1-2**. Outside air now only has to be heated to 8°C lowering the annual energy consumption to 14 300 kW h Addition of a heat recovery system reduced the energy demand by 72%

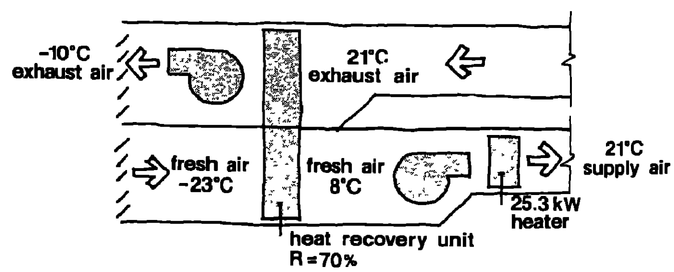


Figure 3 13 3 1-2
Ventilation system with heat recovery

3.13.3.2 Run-Around System

This system consists of two liquid-to-air extended-surface heat-exchanger coils arranged for counterflow, and a pump Before conditioned air is exhausted, it is passed through the recovery coil Water, oil or glycol solution in the exhaust air coil cools the wasted air and transfers recovered heat to the fresh-air preheat-coil

A sensible heat recovery of 50% can be achieved by careful selection of coils Performance of the coils is based on a number of factors that can be readily changed by the designer The following guidelines should serve as a basis for economic selection

—Air velocity should be around 30 5 m/s, liquid velocity around 15 2 m/s
—Average liquid temperature will always be half of the difference between indoor and outdoor air temperatures.
—The largest logarithmic mean temperature difference (LMTD) is achieved if the air and liquid temperature rises are equal.
—If the temperature rises are equal, it can be shown that 0 14 L/s of water or 0.16 L/s of glycol solution has to be circulated for each 472 L/s of air for 27°C design temperature difference, regardless of

performance of number of coil rows. This can be accomplished by regulating the liquid flow.
—Leaving air should not be cooled below −1°C to avoid formation of ice on the exhaust coil, unless indoor humidity is very low
—For —26°C freezing point, the solution should contain 45% glycol by weight This will require 20% more circulation than water and the friction head will increase to 1.7 times that of water

The total heat (enthalpy) recovery performance of the run-around system, including both sensible and latent recovery, will be 40% during winter and 18% in summer. These reductions in required heating and cooling plant capacities should be considered when sizing the plants

The two values of heat recovery— 40% in winter, 18% in summer— represent minimum efficiencies, as differences in dew point temperatures and, thus, in specific humidities are maximum between indoor and outdoor air at design outdoor conditions. Maximum heat recovery will occur when outdoor and indoor specific humidities are equal and, since no latent heat recovery is needed, the total heat recovery efficiency is the same as sensible efficiency, namely 50%.

To obtain more accurate results, meteorological data, not readily available at present, on frequency distribution of hourly total heat (enthalpy) of outdoor air throughout the year would be required. The total heat recovery efficiency could then be calculated for each value of total heat of outdoor air and the weighted average efficiency determined.

3.13.3.3 Air-to-Air Wheel

The air-to-air wheel is an adaptation for air conditioning of the Ljungstrom heat-exchanger This device has been used extensively for 50 years in thermal generating power plants, recovering heat from combustion gas to preheat combustion air It is a regenerative type heat exchanger consisting of a wheel-shaped rotor mounted on a supporting frame. The rotor is approximately 300 mm deep and filled with knitted and corrugated aluminum or stainless steel wire-mesh medium It is driven by an electric motor at approximately 20 r/min The medium is packed so that only about 3% of the volume is medium and 97% is void.

The rotating wheel is alternately exposed to warm and cold air streams and transfers heat from the warmer to the colder stream The two air streams are maintained in separate ducts Cross-contamination can be controlled to less than 1%.

Tests conducted by manufacturers and independent laboratories resulted in over 80% sensible heat recovery efficiency. Here we will assume 75% sensible efficiency. Sensible performance of air-to-air wheels is shown diagrammatically in **Figure 3.13.3.3-1**.

In contrast to the run-around system, rotating air-wheels transfer a considerable amount of moisture. Tests indicate that this averages 60% whenever condensation occurs in the exhaust stream The total heat recovery will be 68% in winter and 27% in summer.

Again, until more accurate information is available, as discussed in detail for run-around systems, we may assume that total seasonal heat recovery efficiencies are 71% for heating and 51% for cooling

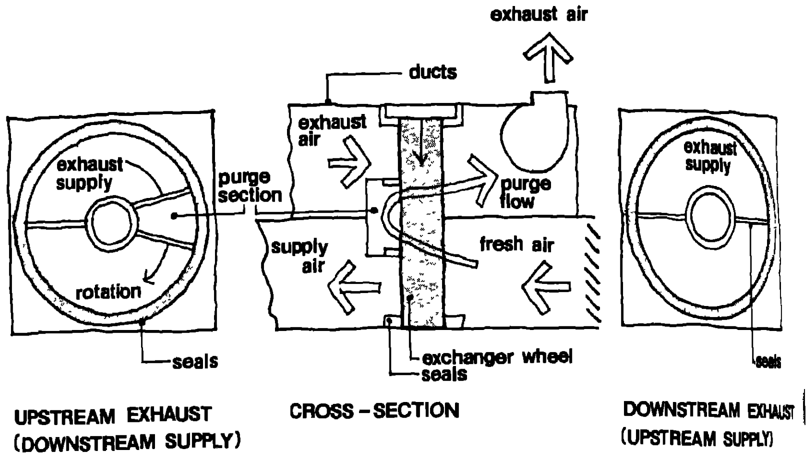


Figure 3.13.3.3-1
Thermal wheel heat exchanger, sections

3.13.3.4 Stationary Heat Exchangers

A number of simple heat exchangers can also be used to recover exhausted heat Figure 3.13.3.4-1 illustrates the operation principle of the finned type heat exchanger This type of heat exchanger has no moving parts Hot exhaust air passes through alternate finned channels, while cold incoming air passes in the opposite direction through the adjacent channels As with the heat wheel, a dust accumulation on the heat exchanger surfaces will substantially reduce the efficiency of the heat

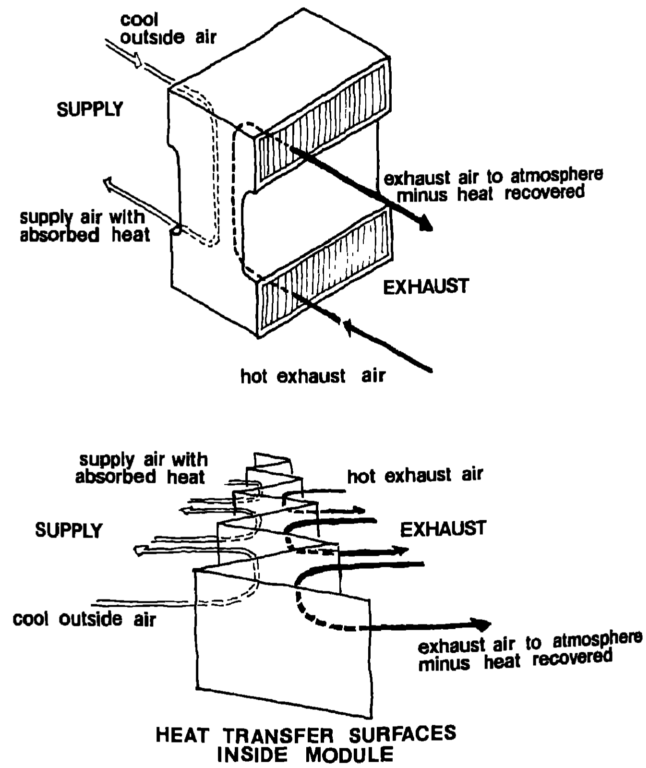
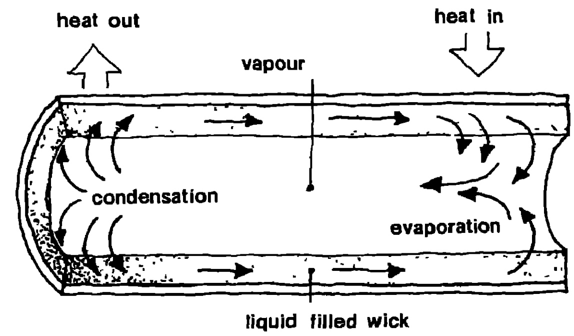


Figure 3.13.3.4-1
Finned type heat exchanger

The 'heat pipe' is another type of stationary heat exchanger A refrigerant and a capillary wick are permanently sealed inside a metal tube setting up a liquid-to-vapor-to-liquid circulation loop **Figure 3.13.3.4-2**. Thermal energy applied to either end of the pipe causes the refrigerant to vaporize The refrigerant vapour then travels to the other end of the pipe where the vapour condenses into a liquid again and gives up its heat The condensed liquid then flows back to the opposite end through the capillary wick. All the energy transferred results from that due to the latent heat of vaporization of the refrigerant

The evaporation-condensation cycle is continuous as long as there is a heat source at one end of the pipe and a medium into which the heat can be dissipated at the other end



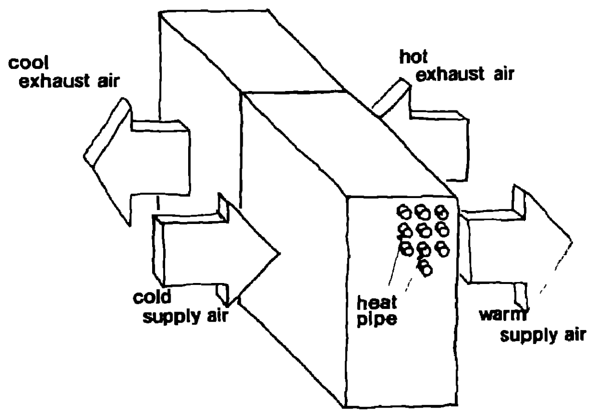


Figure 3.13 3 4-2
Heat pipe heat exchanger

3.14 Lighting

3.14.1 Sources and Energies Required

Consumption of electrical energy for lighting is at such a high level that a wide variety of opportunities is available for conservation

Any attempt at improving energy efficiency must, at least, include consideration of the following

Lighting levels. Too much light is often provided in all areas of buildings Switching off various areas according to need will reduce the total energy used for lighting

Efficiency of sources. New technology has given the lighting specifier a choice between different types of light source Some will produce equivalent quantity/quality of light for less energy use Choice is made on the basis of capital cost, suitability of light quality for the specific task, and ease of replacement, cleaning and maintenance

Control of on/off cycles. No longer does the energy-conserver rely on human willpower to switch off lighting when it is no longer needed Sophisticated and simple on/off and cycling devices now offer a totally automated solution to reduce wastage

Heat gain and cooling load. In making adjustments to lighting installations, the effects of heat gain and cooling load caused by lighting design, should be taken into consideration

3.14.1.1 Typical Efficiency of Lamps[5]

Calculations show that in a typical industrial location, over four times the kW h consumption is needed to light with incandescent compared with 1000 W high pressure sodium, providing the same level of illumination

This demonstrates the obvious need to be aware of the efficiency in lumens per watt of various light sources Final choice should be determined by mounting height, nature of task and colour of source as indicated by colour rendering index (CRI)

The most efficient low pressure sodium with a CRI of 10 and a yellow orange colour is quite acceptable for highway lighting but would be most inappropriate in a beauty salon.

TYPICAL EFFICIENCY OF LAMPS

Source	*Range lm/W	**CRI
Low pressure sodium (35 W to 180 W)	80 to 150	10
High pressure sodium (70 W to 1000 W)	64 to 130	20
Metal Halide (175 W to 1000 W)	67 to 116	50
Fluorescent (30 W to 215 W) 600 mm to 2400 mm U shape, cool white	54 to 76	59-97
Mercury (100 W to 1000 W) colour corrected	35 to 59	45
Incandescent (100 W to 1500 W) Basic reflector, par, indicator	17 to 23	95+

*Lumen per watt is the measure of the efficiency of a light source Ballast losses are included where applicable
**CRI-Colour Rendering Index (of a light source) is measured on a scale of 0-100 with 100 considered best for colour rendition It is a measure of the degree to which the perceived colour of objects illuminated by the source conforms to those of the same objects illuminated by a reference source for specified conditions

Table 3.14.1.1-T_1
Typical efficiency of lamps.[1]

Lamp lumen depreciation of the lamps also affects energy use High pressure sodium, fluorescent, and incandescent lamps have good lumen maintenance characteristics Metal halide and mercury lamps depreciate somewhat faster in light output throughout their life (Reference should be made to manufacturer's data for each specific lamp type and size.)

The difference in light per watt can have a dramatic effect on energy required to operate a lighting system For example, **Table 3.14.1.1-T_2** shows the energy required to light a facility of 929 m^2 to 1080 lx for 4000 h/a

ENERGY TO LIGHT A FACILITY	
Source	**kW·h Required**
1000 W incandescent	280 000
400 W deluxe mercury	194 400
F40 fluorescent	132 240
400 W metal halide	125 120
400 W high pressure sodium	79 800
1000 W high pressure sodium	67 800

Table 3 14 1 1-T_2
Energy required to light a facility of 929 m^2 to 1080 lx for 4000 h/d

.1 **Incandescent Lamps:** When incandescent lamps are required for colour and control reasons, wherever possible a few high wattage lamps should be used rather than many low wattage ones A single 100-W lamp (1740 lm) produces more light than two 60-W lamps (at 855 lm/lamp, 1710 lm) Similarly, the use of 'general service', rather than 'extended service' lamps is also energy conserving The 750-h general service 100-W lamp produces 17 4 lm/W and the same size 2500-h extended service lamp produces only 14 8 lm/W 17.5% more lamps and power are required to produce equivalent illumination with the long service type

.2 **Fluorescent Lamps:** A basic rule of thumb in selecting fluorescent colours is to use warm colours below 550 lx, cool colours above 550 lx

FLUORESCENT LAMPS			
Apparent colour temperature	**Standard**	**Excellent**	**Special**
2800°C-3000°C	Warm White (WW) 3200 lm CRI-59	Warm White Deluxe (WWX) 2200 lm CRI-85 New Improved Warm White 3400 lm CRI-85	Warm White Specials 1700 lm CRI-59
400C°C	Cool White (CW) 3200 lm CRI-66	Cool White Deluxe (CWX) 2200 lm CRI-89 New Improved Cool White 3400 lm CRI-85	Cool White Specials 1700 lm CRI-97
5000°C-6000°C	Daylight (D) 3200 lm CRI-79	Daylight Deluxe (DX) 2200 lm CRI-89	Daylight Specials 1700 lm CRI-97

Table 3.14 1 1-T_3
Fluorescent lamps [2]

3.14 Lighting

The selection of the fluorescent lamp is often based on colour (Colour Rendering Index, CRI) with little note of the lumen output In this regard, a comparison between the cool white special and the cool white (CW), commonly used in offices, is of interest While the special provides a CRI of 97, comparing very favourably with the CRI of incandescent, the cool white (CW) has a CRI of 66 However, in terms of lumen output the CW far exceeds the performance of the special, providing 3200 lm of light compared to 1700 lm for the latter

.3 **Reduced-wattage Lamps**: Some types simply reduce light output in approximately the same ratio as they reduce wattage

A relamping and *regular* cleaning plan in addition to installation of reduced-wattage lamps will improve on the efficiency of old style fluorescents with a spot-relamping procedure

A recent fluorescent lamp development is the application of a new high-efficiency phosphor in reduced-wattage 1200 mm and 2400 mm lamps This makes possible the same light output as regular lamps with about 14% reduction in wattage.

The high efficiency reduced wattage lamps have been matched to an improved performance ballast in which the losses are cut in half The total wattage reduction is 19% and these lamps retain the light output of standard systems Another innovation is a 75-W ellipsoidal incandescent reflector lamp which delivers the same useful light as the 150-W R40 in deep-baffled downlights

There are also types of lamp that reduce wattage and provide increased output at the same time

For example, interchangeable metal-halide lamps can be substituted for the same wattage mercury lamps in most sockets (depending on the ballast) to produce about 40% more light in the 400-W size and 93% more in the 1000-W size

Similarly, the interchangeable 160-W high pressure sodium lamp can be substituted in most 175-W mercury sockets to save 15-W and produce 10 800 mean lumens versus 7650 for mercury

The 215-W interchangeable high-pressure sodium lamp van be substituted in most 250-W mercury sockets to save 35-W and produce 17 100 mean lumens versus 10 400

.4 **Luminaires**: Luminaires should be selected on the basis of energy efficiency—see ASHRAE 90-75[3] for minimum recommended coefficient of utilization (CU) Typical values of CU for various types of luminaires can be found in Figure 9-12 of the IES Lighting Handbook (5th ed).[4]

Thermal controlled luminaires—air or water cooled—permit a portion of the heat to be removed before it can enter occupied space in warm weather Conversely, the heat can be utilized in this space in cold weather

3.14.1.2 Building Interior Surfaces Reflectance

A major factor in the efficiency of any lighting system is the reflectivity of walls, ceilings, floors and furniture Dark colours absorb light, while light colours reflect and contribute to the general visual comfort of an area. A brighter colour will usually mean less lighting is required, thus saving energy and money This subject is discussed further in **Section 4.5.3.1.**

If an office or building is to be re-decorated consider repainting in light colours Most tinted shades are acceptable Cool shades (greens and blues) reflect more light than warm shades of beige, pink or coral Table 3.14.1.2-T_1 provides a reference for recommended surface reflectances related to lighting efficiency

Most paint manufacturers offer guidelines on the reflective qualities of the products. It should also be remembered that highly reflective, high gloss finishes produce glare, visual discomfort and eye strain.

RECOMMENDED REFLECTANCE VALUES	
Ceilings	80% to 90%
Walls	40% to 60%
Furniture	25% to 45%
Floors	20% to 40%

Table 3 14 1 2-T_1
Recommended surface reflectances related to lighting efficiency

3.14.1.3 Control Devices

.1 **Photo-electric Controls and Automatic Timing Devices:** Applications of outdoor lighting vary from parking area lighting to building, sign and equipment storage flood-lighting

Photo-electric controls and automatic timing devices have found increasing acceptance in commercial parking areas and building floodlighting They are also used extensively for the control of perimeter security illumination

Similarly, the more flexible automatic timing devices can limit sign and show-window lighting, building and area flood-lighting to time periods when their effective lighting is more useful

All unnecessary lighting should be shut off during the early morning hours when the use of lighting energy is wasteful

.2 **Time Switches:** These are simple, rugged energy saving devices. The most suitable type has a spring loaded component in case of power 'OFF' in the electrical system. Switches should keep the correct time for 24 or 36 hour periods to eliminate constant time setting, and reliance on the human element The specific needs of an installation must be considered in order to gain the timing flexibility required Several types of switch are available, including those with the ability to control the same on-off times daily, skip selected days when not required and provide seven-day control with the flexibility of different on-off times for each day

.3 **Photo Cell:** The photocell control ensures light at night For special applications, it can be calibrated to come on during temporary dark periods during the day These devices can be used in combination to save energy. A timer can be used with the photocell, controlling mainly outdoor lights or display windows. The two devices should be connected so that the photocell switches the lights 'ON' approximately one half hour after sunset and the time switch will switch the lights 'OFF' at any desired time.

The photocell has been utilized in another control which can save energy. This one has a photocell sensor which reads illumination levels and converts the reading into a signal to alter power input in

special dimming ballasts These then, continuously and automatically, adjust lamp lumen output to a predetermined value As lamp lumen depreciation lowers illumination, the device automatically compensates by increasing lamp power Also, if ambient daylight increases total room illumination, lamp power is reduced automatically

.4 **Dimmers**: Solid state dimmers allow the most efficient use of light, providing greater control than the three-way bulb, another effective control device

LIGHT SOURCE DATA COMPARISON						
Light Source	Lamp wattage	Typical Total watts	Mean lumens	Rated lamp life (hours)	Installed, lumens watts (average)	Colour Appearance per Rendition
Incandescent	300	300	5 800	1 000	19	Warm but White
	500	500	10 000	1 000	20	Excellent
	1000	1 000	21 000	1 000	21	
Fluorescent	2-40 (430 mA)	97	5 290	20 000	55	Cool to Warm White
	2-75 (430 mA)	181	11 340	12 000	63	Very Good
	2-60 (800 mA)	140	7 400	12 000	53	
	2-110 (800 mA)	268	15 820	12 000	59	
	2-110 (1 500 mA)	267	11 000	9 000	41	
	2-165 (1 500 mA)	385	15 600	9 000	41	
	2-215 (1 500 mA)	480	24 800	9 000	52	
Mercury	100	125	3 500	24 000	28	Bluish White to White
	175	205	7 500	24 000	36	Acceptable
	250	285	11 100	24 000 +	39	
	400	150	19 800	24 000 +	44	
	2-400	875	39 600	24 000 +	45	
	1 000	1 070	47 900	24 000 +	45	
Metal halide	175	215	10 800	7 500	50	Bright White
	250	300	17 000	10 000	57	Good
	400	450	25 600	20 000	57	
	1 000	1 080	90 200	12 000	83	
	1 500	1 625	142 600	3 000	88	
Super metal halide	400 (Vertical Operation)	450	32 000	15 000	71	Bright White Good
	400 Horizontal Operation)	450	32 000	20 000	71	Bright White Good
	1 000 (Vertical only)	1 080	100 000	12 000	92	Bright White Good
High pressure sodium	50	60	2 970	24 000	50	Warm Golden White
	70	94	5 200	24 000	55	Acceptable
	100	135	8 550	24 000	63	
	150	195	14 400	24 000	74	
	200	250	19 800	24 000	79	
	250	303	24 750	24 000	82	
	400	470	45 000	24 000	96	
	2-400	950	90 000	24 000	95	
	1 000	1 095	126 000	24 000	115	
Deluxe high pressure Sodium	250	303	22 500	7 500	74	Closest to Incandescent
	100	Data Not Available Yet				
Low pressure sodium	18	40	1 800	10 000	45	Amber Yellow Limited
	35	64	4 800	18 000	75	Interior Applications
	55	80	8 000	18 000	100	
	90	125	13 500	18 000	108	
	135	163	22 500	18 000	138	
	180	205	33 000	18 000	160	

Table 3.14.1.4-T_1
Light source data comparison [5]

3.14.1.4 Daylight and Perimeter Lighting

Daylight should be utilized for illumination wherever possible Multi-glazing and improved reflective, absorptive, and insulated types of glass have removed some of the thermal transmission problems previously associated with natural lighting (Ref **Section 3.6.5** Glazing, **Section 3.14.4** Daylighting, and **Section 4.9** Protective Elements)

Light penetration into the interior of the building can be assisted, for example, by venetian blinds, which can reflect and direct daylight and also reduce glare

In areas where codes, or design considerations establish sizable amounts of glazing, the luminaires at the perimeter should be on a separate switch, or photo cell to permit operation only when there is insufficient natural light In major multi-story office buildings or schools approximately 25% of the energy normally used for lighting can be saved if the perimeter is handled in this manner

COST ANALYSIS

Lighting System Description	High Pressure Sodium 400-W	Metal Halide 400-W	Super Metal Halide 400-W	Mercury (Deluxe) 1000-W	Fluorescent SHO 2-Lamp 2400 mm	Incandescent I F 1500-W
1 Rated initial lamp lumens per mixture	50 000	34 000	40 000	63 000	31 000	34 400
2 Rated lamp life, hours, at 10 h per start	24 000	20 000	15 000	24 000	9 000	1 000
3 Watts per lamp	400	400	400	1 000	215	1 500
4 Input watts per fixture (including ballast losses)	470	460	460	1 080	480	1 500
5 Coefficient of utilization	0 76	0 76	0 76	0 70	0 70	0 70
6 Lamp depreciation factor	0 90	0 78	0 78	0 76	0 80	0 66
7 Dirt depreciation factor	0 86	0 87	0 87	0 83	0 83	0 83
8 Effective maintained lumens per mixture (*1* × *5* × *6* × *7*)	29 400	17 500	20 629	27 800	14 400	13 200
9 Desired average lux on work surface	756	756	756	756	756	756
10 Area per outlet, m² (*8* – *9*)	39	23	27	37	19	175
11 Total fixture for equal maintained lux (area – *10*)	24	40	34	25	48	53
12 Total wattage installed (*11* × *4*)	11 280	18 400	15 640	27 000	23 040	79 500
13 Net cost of one fixture, $	165	110	110	137	90	55
14 Wiring and distribution cost per fixture @ 100/kV A, $	47	47	47	108	48	150
15 Installation labor cost per fixture, $	20	20	20	20	25	20
16 Net lamp cost per fixture $	60	29	34	31	14	8
17 Total system initial cost, $ (*13* + *14* + *15* + *16* +) × *11*)	7,008	8,200	7,140	7,400	8,496	12,349
18 **Annual system owning cost, $** (11 75% of (*13* + *14* + *15*) × *11*)	823	964	839	870	998	1,451
19 Burning n/a	5 000	5 000	5 000	5 000	5 000	5 000
20 Number of lamps spot replaced per year no group relamping (*19* × *11*) × No of lamps per fixture) – 2	5	10	11	5	53	265
21 Lamp replacement cost per year, $ (*20* × net cost per lamp)	300	290	385	161	373	2 120
22 Labour cost for spot replacements, $ (*20* × spot labour rate per lamp at $5.00 lamp)	25	50	57	26	265	1,325
23 Annual energy cost per year, $ (*12* × *19* × *3*¢/kW h 100 000)	1,692	2,760	2,346	4,050	3,456	11,925
24 **Total annual operating cost, $** (*21* + 22 + *23*)	2,017	3,100	2,788	4,237	4,094	15,370
25 **Total annual cost, owning and operating,** $ (*18* + *24*)	2,840	4,064	3,627	5,107	5,092	16,821
26 Relative total annual cost for equal maintained lux, $	1 0	1 43	1 28	1 8	1 8	5 92

Table 3 14.1.4-T_2

Cost analysis of a typical new installation 929 m² area, 756 lx maintained.[6]

3.14.2 Heat Gain and Cooling Load

3.14.2.1 Water Cooled Luminaires Systems

Removal of lighting heat by air extraction has proved effective for buildings with up to 1000 lux or so of illumination Removal of lighting heat by circulation of non-refrigerated water through water-jacketed fixtures has been used in buildings with lighting loads of 55 W/m^2 and higher The water-cooled fixtures are equipped with housings formed to provide integral water passages, similar to older refrigerators.

For this approach to be feasible economically, there needs to be an ample supply of non-refrigerated water, and the chiller has to operate as a heat pump to utilize the recovered lighting heat Effective sources of cooling water have been evaporative coolers (in dry climates) and natural sources such as rivers. The water needs to be relatively cool to reduce the amount of water that has to be circulated, and hence reduce pumping energy The designers of several federal building installations have reduced initial costs of water-cooled-luminaire systems by utilizing the piping of the fire-protection sprinkler system to circulate water to the luminaires

In some installations, aluminum, water-filled window louvers have been connected into the system These louvers intercept solar heat where it is not wanted (such as on a southerly or westerly facade), and the collected heat is combined with that from the water-cooled luminaires and delivered to louvers on facades that need heat at windows In warm weather, the louver heat is rejected along with that from the luminaires.

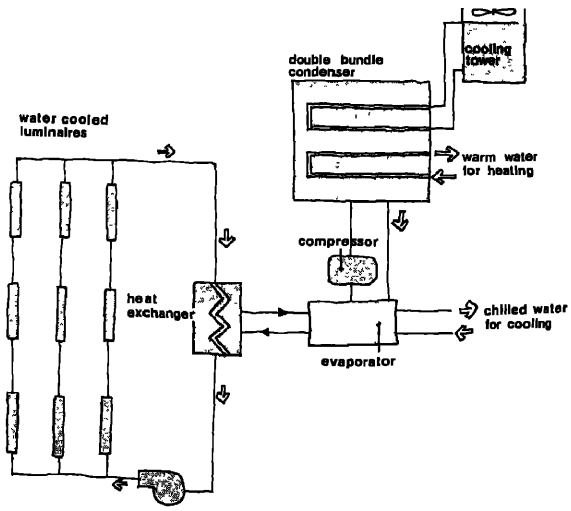


Figure 3.14 2 1-1
Water cooled luminaires [7]

3.14.2.2 Tempering Cool Supply Air System

The heat from lights can be reutilized in several ways In cold weather, for example, heat absorbed by the chiller from air returned from interior spaces can be circulated to perimeter spaces to counteract heat loss It can be captured at any time of the year with one type of air-terminal system utilizing air-powered induction units

Primary cool air is supplied to these induction units to provide the maximum cooling effect required for any particular space In other words, the primary air handles the maximum cooling load But if the lights are turned off or the space is unoccupied (in a conference room, for example), the primary air flowing through the induction box induces as much of the warm plenum-space air as is needed to maintain comfort conditions in the space, and the primary air is reduced in proportion The ratio of primary air to plenum air is controlled by thermostatically-actuated dampers in the induction box

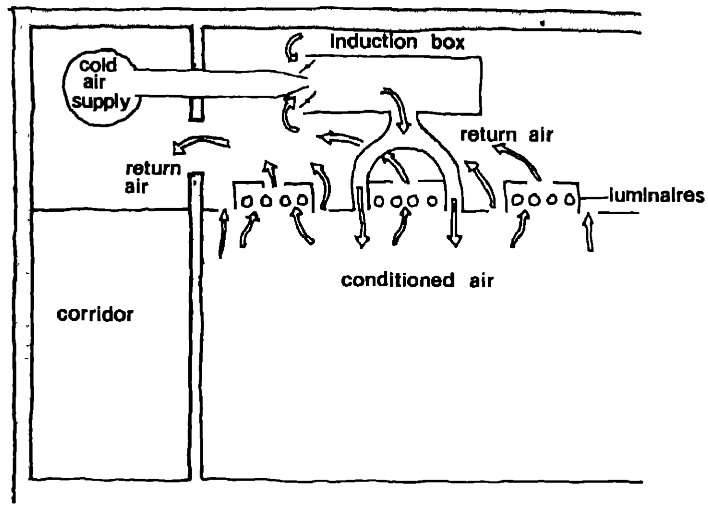


Figure 3 14 2 2-1
Air handling system[10]

3.14.3 Installation Options

3.14.3.1 Lighting Levels

Lower lighting levels also result in direct energy saving Quality of Illumination, rather than higher intensity, should be the goal.

Since the largest reductions in levels are possible in less-occupied locations, light intensity in task areas need not be lowered beyond the visual acuity required for specific tasks.

Recent experiments confirm that lighting levels between 110 lx and 440 lx in certain instances are sufficient for visual acuity and physiological needs, a considerable reduction from the 650 lx to 1620 lx now being provided in many buildings

.1 Task Areas: The lighting level should provide proper illumination for the task to be performed. In adjacent non-working areas lower lighting levels are possible.

.2 Non-Task Areas: General lighting in areas surrounding task locations need an average lighting level of one third the level of the task lighting—but not less than 200 lx.

3.14 Lighting

LEVELS OF ILLUMINATION			
	Illuminating Engineering Society 9-80	Ontario Hydro Energy Conservation Standard	
Work Station or Area	lux on Task	Nominal lux Levels	lux Range
Industrial			
*Vehicle service bays	300	300	250 [illegible]
Tool cribs	500	400	350 [illegible]
Active stores areas	200	200	150 [illegible]
Check out counter	1100	550	500 [illegible]
Shipping and receiving	200	200	20[illegible]
Switchgear areas (metal clad and cubicle switchgear)	300	300	250 [illegible]
*Machine shops	500	500	450 [illegible]
Foreman s offices	700	550	500 [illegible]
Guardhouses		550	500 [illegible]
Laboratories			
*Main laboratories	1100	700	650 [illegible]
*Metallurgical, non-destructive testing special invest labs	1100	800	700 [illegible]
*Balance, calorimeter, colorimetry microscope rooms, workshops	1100	800	700 [illegible]
Outdoor lighting			
Parking	20	20	
Unloading areas (task only)	20	100	
Building entrance	50	100	
Approach roadways	15	5	
Pedestrian gates	50	100	
Vehicle gates	50	50	
Active storage areas	20	50	
Inactive storage areas	10	20	
Office and General areas			
Active official areas clerical typing invoicing etc	1100	700	65[illegible]
Drafting areas	1600-2200	900	8[illegible]
Typing pools	1100	700	65[illegible]
Engineering office areas	1100	700	65[illegible]
Printing areas		700	65[illegible]
Elevators	200	100	
Washrooms	300	200	15[illegible]
Mail rooms (sorting reading)	1100	550	5[illegible]
Locker rooms	200	200	15[illegible]
Rest rooms		300	25[illegible]
Medical and first aid consulting rooms	500	550	5[illegible]
Active records areas	100-200	550	5[illegible]
Stores areas	500	200	15[illegible]
Shipping and receiving areas	200	200	15[illegible]
Mechanical equipment rooms	200	200	15[illegible]
Indoor parking	100	50	
Telephone switchboard rooms (attended)		550	5[illegible]

*To be supplemented with task lighting as required

Table 3 14 3 1-T_1
Levels of illuminations currently recommended [9, 10]

.3 **Non-Critical Lighting:** In circulation and seating areas where no specific visual tasks occur, a lighting level of one third the level of the average general lighting in the adjacent task spaces should be provided but not less than 100 lx.

.4 **Utilizing Lower Light Levels:** There are substantial savings to be realized by designing with lower light levels

For example, an office area of 30.5 m by 30.5 m with 352 two-lamp luminaires provides a 1000 lx maintained lighting level with [illegible]

power requirement of 37 9 W/m^2 The same area with a revised lighting layout incorporating 182 two-lamp luminaires in a coffered ceiling and providing a 700 lx lighting level will have a power requirement of 19 6 W/m^2—representing a saving of 48% in the power required

Capital costs are reduced through savings in the purchase of.
—fewer luminaires
—fewer lamps
—smaller capacity HVAC equipment because of reduced heating load generated by the lighting fixtures

Operating costs are reduced because
—less power is required
—power demand charges are lower
—there are fewer fixtures and lamps to be cleaned
—there are fewer lamps and ballasts to be replaced (re-lamping is necessary approximately every 4 years and ballast life is approximately 12 years)

3.14.3.2 Implementing Task Lighting

Inadequate illumination on a task often results when the lighting layout is not co-ordinated with the room function or conversely the room layout is not co-ordinated with the lighting layout

General practice has been to provide a ceiling lighting layout that is permanent, while the floor working space layout has become very flexible, especially in large open plan areas As described earlier, adequate lighting should be provided at the task with a much reduced lighting level in adjacent and service areas. However, lights are normally controlled in banks from a local lighting panel and, when the room function is changed, turning off surplus lights is not a simple operation An electrician is required to dissemble the fixture, disconnect the ballast, and then re-assemble the lamps, the lens, the reflector and any other parts which had to be dismantled

Experience suggests that on the next change of room function, which could follow within a week or month, the luminaire which was turned off is required to be turned on again, with the resulting expense of re-connection

The costly procedure just described could be eliminated by the addition of an inexpensive switch installed in the luminaire With this switching system the lighting layout could be quickly altered to suit the revised floor layout and provide the required level of illumination where it is needed.

The switch could be an on-off toggle, pull chain, push button, or other type to suit local requirement. It could be installed inside the fixture under the louver, outside of the fixture or on the side or top of the fixture, where it would be readily accessible. (The pull chain switch could be extended below the louver so that it could be operated from the floor with a pull hook)

The push button switch could be installed under the fixture louver in such a way that when the lens or louver is pushed up the switch would turn the lights or the ballast on or off. This switching system is applicable to new projects as well as existing facilities which are to be modified. The potential cost savings which could result from a typical installation are demonstrated in the following example.

.1 **Sample Cost Saving and Payback Period Calculation for Task Lighting Switching**: This calculation is based on an existing installation of 4-40 W fluorescent luminaires, a high level of illumination Approximately 50% of the 2 lamp ballasts are to be disconnected without reducing the level of illumination at the task

The following assumptions are made.

—the cost to provide and install the switch is $5 50 per two-lamp ballast
—power demand for 2-40 W lamps with ballast is 100 W
—the lights are turned on for 3600 h/a
—the cost of demand power per month is 2 50/kW
—the cost of power is $0 025 kW h

Requirement:

Supply and install approximately 1 650 switches in the fluorescent fixtures shown on the drawings to be disconnected Each switch is to control one ballast

Estimated Cost per Switch $5 50

Sample Cost Saving and Payback Period Calculation=
Implementation Cost (1650 × $5 50) = $9,075 00

Reduction in Power Demand

$$\frac{1650 \text{ ballasts} \times 100 \text{ watts per ballast}}{1000} = 165.0 \text{ kW*}$$

Saving in Cost Penalty in Demand
$2 50 per kilowatt per month × 12 months × 165 0 = $4,950

Reduction in Power Consumption per Year
165.0 kW* × 3600 h/a operation = 594 000 kW h

Reduction in Power Consumption Cost per Year
594 000 kW h × $0 025 kW h = $14,850

Total Savings = . $19,800

Payback Period

$$\frac{\text{Implementation cost}}{\text{Yearly saving}} \text{ a} = \frac{\$\ 9{,}075}{\$19{,}805} \text{ a} = 0.46 \text{ a (24 wks)}$$

3.14.3.3 Flexible Switching

If the lighting is not an integral part of the heating system the lights should be turned off when they are not needed for illuminat.. In individual offices a reasonable estimate of lighting time saved in this way would be 40% of a typical 14 hour 'lights on' day

In an area with three fixtures 60 mm × 1 200 mm with 4-40 W lamps the payback period to install a local switch in an existing building . just within the typically accepted three year payback period

3.14.3.4 Exit Stair Lighting and Circuit Control

In buildings with elevators, the accepted practice is for people and material to move vertically in elevators, and the emergency building exit to be provided by the stairs

Typically, stairway lighting is provided by luminaires located at each floor and at each intermediate landing. Normally, this lighting is on twenty-four hours a day, seven days a week even though people almost never use the stairs.

Stairway lighting should be to the approval of the local authority but the lighting level should be minimal from an efficient light source and the circuit controlled by an approved arrangement Where possible building design should take advantage of daylight in the stairways Reference should also be made to **Section 4.5.4** regarding the stairways and spatial design.

3.14.3.5
Cleaning of Luminaires

In a Toronto office building, fluorescent luminaires with 4-40 W cool white lamps providing 800 lx to 860 lx before cleaning have provided 1100 lx after proper cleaning; an increase of 25%.

Similar luminaires in other conditions providing 610 lx before cleaning, have provided 1200 lx after proper cleaning; an increase of almost 100%

A minimum specification for fixture cleaning should include the following

—Clean the lighting fixtures with cleaning solution, or mild detergent.
—Wash all reflectors, reflecting surfaces, plastic panels and louvers, glass panels and lamps with the detergent and rinse with clean water, using separate wash and rinse tanks for removable components
—Use a natural sponge or a chamois for the wash operation and a separate natural sponge or a chamois for the rinse operation. Air dry components before re-assembly.

3.14.3.6
Relamping

Relamping should be carried out in a group relamping program at approximately 75% of the rated life of the lamp. Spot replacement of burned out lamps may be done once a month in large areas or immediately in small offices

Group relamping in a general office could be expected every four years depending on the rated life of the lamps (fluorescent lamps about 18000 h) and the number of hours the lamps are turned on (about 4000 h/a)

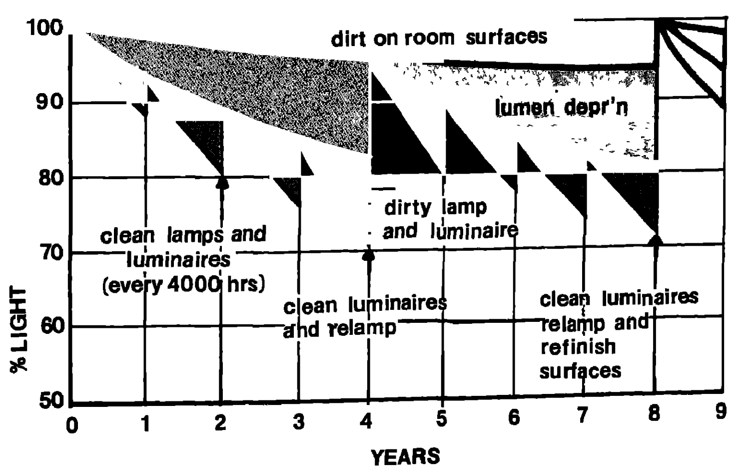


Figure 3.14.3.6-1
Effect of cleaning and relamping [11]

3.14.4 Daylighting

With the current emphasis on energy conservation, the unique properties of daylighting as a source of illumination are once again being recognized

Daylighting has the potential for saving vast quantities of energy that might otherwise be used in the lighting of buildings

3.14.4.1 Effect of Daylighting

The extent to which daylight will assist in the reduction of energy consumption is dependent upon a number of variables such as its availability, building orientation, size and location of light openings and the levels of lighting required

During the summer, solar energy used for lighting can add to the energy consumed for cooling purposes, particularly if uncontrolled However, in a properly designed building its total effect is beneficial, providing heat that can substantially reduce the building's use of energy in winter (Ref **Section 3.1** Heat Gain and **3.10** Solar Energ Technology)

Reference has been made elsewhere in this Handbook **Section 3.6.5** to the efficiency of sunlight as a source of illumination It provides more light per unit of energy (and per unit of heat) than do m[illegible] varieties of electric light commonly used in buildings The conclusion to be reached is that considerable reductions in energy consumption are possible through proper use of daylight for lighting in efficiently designed and operated buildings

Table 3.14.4.1-T$_1$ shows that daylighting produces more lumens per watt than electric lighting of the more common varieties and, in terms of air conditioning needs, that daylighting requires less cooling per unit of light produced

LIGHT OUTPUT AND EFFICACY			
Source of Illumination	**Light output lm/m²**	**Efficacy lm/W**	**Air Cond**
Daylight through high-transmittance glazing	57 282	106 (transmitted)	0 27
Daylight through medium-transmittance glazing	33 804	196 (transmitted)	0 27
Incandescent light	—	20	1 90
Fluorescent light	—	60	0 63
High intensity discharge light	—	35-130	
*t/(lm × 10⁵)			

Table 3 14.4 1-T$_1$
Light output and efficacy for several daylighting and electric light sources[12]

3.14.4.2 Combining Daylight and Electric Light

For most new construction, electric light will have to be used in conjunction with daylight to illuminate interior areas adequately and to provide suitable lighting at night and on dark, overcast days The question is not whether to use daylight or electric light—the two sources are compatible and complimentary—but how this should be combined in order to produce optimum results for the conditions involved.

3.14.4.3 Architectural Elements

Architectural elements used for daylight control include the various opaque structures, screens, shades, and draperies which intercept light They include building overhangs, vertical fins, and similar building elements, as well as opaque and translucent screens, shades or curtains, trees and other landscaping elements (Ref. Section 4.9 Protective Elements)

Control elements applied to the exterior of buildings generally are the most effective from the standpoint of heat control as they transmit most absorbed heat to the exterior air where it is carried away However, used on the exterior, they are exposed to weather and pollution and require an adequate maintenance program

Elements applied to the interior are less susceptible to pollution but tend to absorb and reradiate heat to the interior where it will influence occupants' comfort and/or the air conditioning load.

3.14.4.4 Daylighting and Building Geometry[13]

Research at the University of Texas has shown that energy consumption savings for heating, cooling and lighting of up to 50% can be achieved theoretically through calculation of optimum window areas

Results based on the development of a sky illumination model for a specific location in Austin, Texas, showed that the optimum window area is a sensitive function of.

—Geometry—surface to volume ratio
—Window to wall area

The total energy consumption for heating, cooling, and lighting shows a well defined optimum amount of window area at about 25% of the total wall area

Having discovered the optimum ratios, a real possibility then exists for reducing energy consumption by carefully integrating daylighting, artificial lighting and building geometry

The following were the results of the calculations
As the window area increases relative to the wall area several trade offs begin to occur First, the most obvious, is that the reliance on artificial lighting starts to decrease, and so does that component of the total energy consumption.

In addition the rate of internal heat generation starts going down This internal heat generation that comes from electric lighting can be desirable whenever the reduction in heating cost during the winter is greater than the increase in cooling costs during the summer.

Depending on the specific conditions of the problem, increasing the window size may result in a decrease of energy consumption for heating and cooling.

See Figure 3.14.4.4-1 for example In this case (surface to volume ratio (m^2/m^3) of 1·0 01 the energy consumption for heating and cooling goes down at first as the window area increases. The reduction comes from a lowering of the cooling cost due mainly to the reduction of internal heat generation, and to a lesser extent to the increased ability of the building skin to release this heat through the increasing glass area.

3.14 Lighting

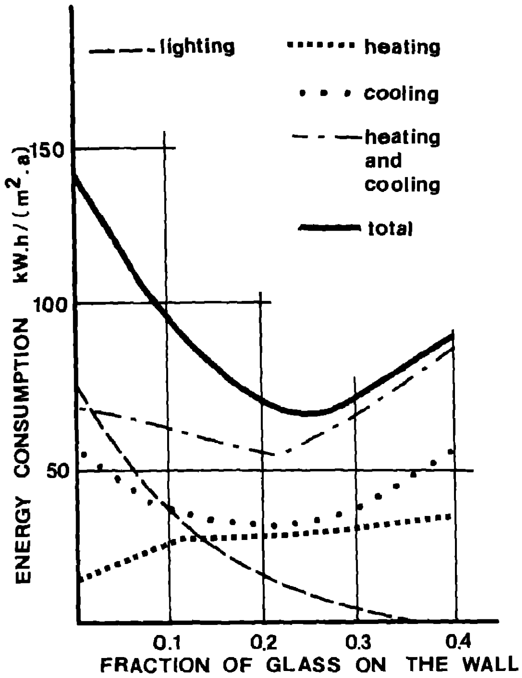


Figure 3 14.4 4-1
Annual energy consumption for heating, cooling, and lighting per unit area of floor as a function of amount of window on the wall for a south facing room with surface to volume ratio of 1'-0 33 The total energy consumption shows a well defined minimum when the window area is 25% of the wall area The windows are shaded from direct sun from March through September[14]

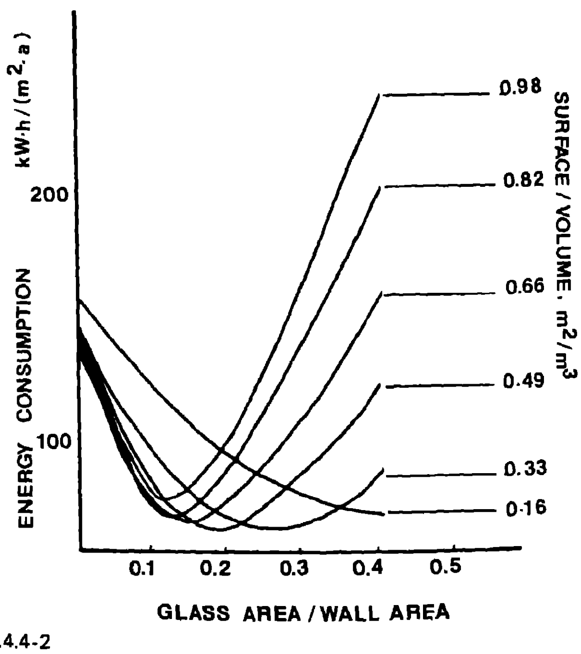


Figure 3.14.4.4-2
Annual energy consumption for heating, cooling, and lighting as a function of glass area to wall area ratio parametric on the surface to volume ratio of the space The figure illustrates the dependence of the optimum glass area on the surface to volume ratio[1.]

In this example, increasing the window area reduces the energy consumption via a tandem effect of reducing electric lighting consumption and reducing cooling costs to remove the internal heat generated by the electric lighting Further increase in the window area starts increasing the air conditioning cost, and at a slower rate the heating cost, with a net rapid increase in the energy consumption for heating and cooling

As the surface to volume ratio of the structure changes the total energy consumption dependence on window area changes, particularly the value of window area for which minimum energy consumption occurs **Figure 3.14.4.4-2** shows the total yearly energy consumption (heating, cooling and lighting) as a function of glass area to the wall area parametric on the surface to volume ratio

This figure shows the presence of the optimum window area for all values of the surface to volume ratio of the structure; however, as the surface to volume ratio increases (e.g as the building gets smaller) the optimum window area occurs at smaller percentages of the total area

Figure 3.14.4.4-2 also indicates the existence of an optimum surface to volume ratio for a given window area to wall area ratio. This dependence is shown explicitly in **Figure 3.14.4.4-3.**

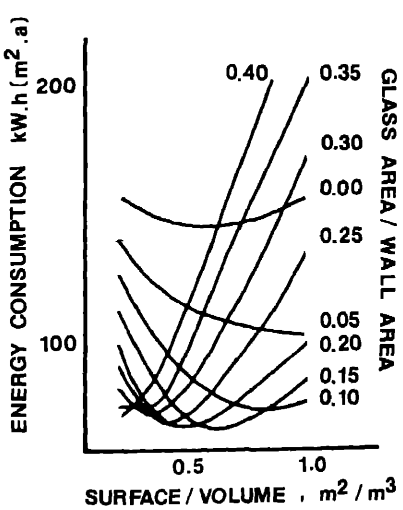


Figure 3 14 4 4-3
Annual energy consumption for heating, cooling, and lighting as a function of surface to volume ratio parametric on the relative window area [16]

For walls with 40% window area the energy consumption shows the expected increase as the surface to volume ratio increases; otherwise it shows the existence of an optimum surface to volume ratio, including the case with no windows

This last effect is symptomatic of the presence of internal heat generation; because as the surface to volume ratio increases, the surface through which the heat can be dissipated increases, thus reducing at first the load on the mechanical equipment. For other values of window area the existence of an optimum surface to volume ratio is due to varying combinations of reduced artificial lighting and improved dissipation of internal heat.

The existence of minimum energy consumption both as a function of window area to wall area ratio and as a function to surface to volume ratio suggests the possibility of using contours of constant energy consumption as a possible design aid Such contours are depicted in **Figure 3.14.4.4-4**.

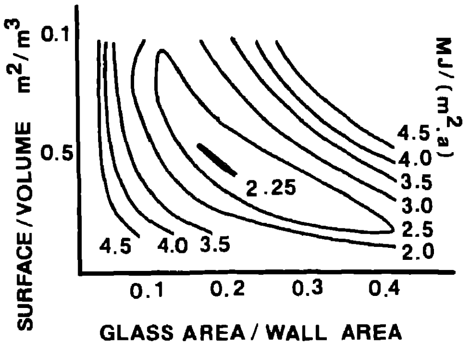


Figure 3 14 4 4-4
Contour of constant total energy cost on the plane defined by the surface to volume ratio and the relative glass area [17]

There is a relatively complex parametric dependence of the energy consumption as the amount of glass in a structure is changed To help visualize the overall dependence **Figure 3.14.4.4-5**, a 3-D diagram, will show the energy consumption as a function of both the surface to volume ratio and glass area to wall area ratio **Figures 3.14.4.4-2,3 and 4** are the projections of this 3-D surface onto the window-cost plane, the surface-cost plane and the window-surface plane respectively

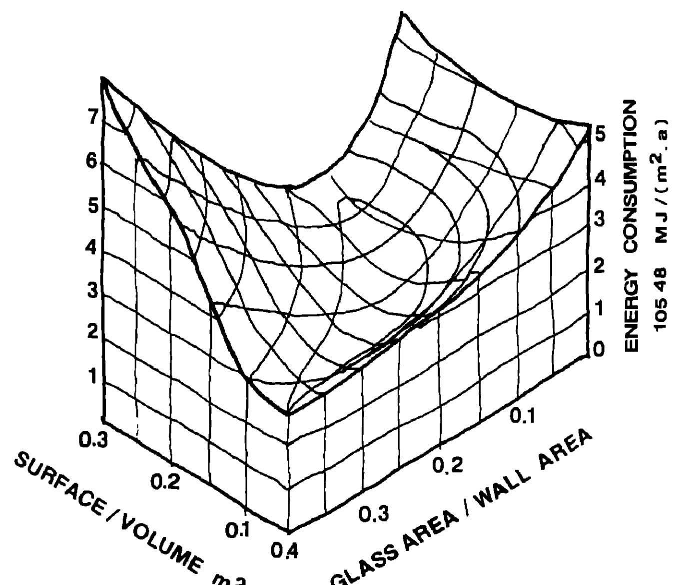


Figure 3.14 4.4-5
3-D Diagram showing the dependence of the total annual energy consumption for heating, cooling and lighting on the relative window area and on the surface to volume ratio.[18]

3.15 Domestic Equipment and Appliances

3.15.1 Energy Consumption and Cost

Today most homes have a wide range of electrical appliances The cost of the electricity they use depends on their wattage, the number of times and the length of time they are operated and the local power rates.

Frost-free refrigerators which run almost continuously and larger wattage appliances such as a stove, water heater, dishwasher and clothes dryer generally contribute the greatest cost to electricity bills Wise and efficient use of such high energy-consuming appliances will have the greatest impact in wattage saving on the cost of domestically-used electricity

AVERAGE WATTAGE, KILOWATT-HOURS AND COST OF ELECTRICITY FOR RESIDENTIAL ELECTRIC APPLIANCES

Appliance	Average Wattage	Monthly Kilowatt hours (approximate)	Monthly* Cost (approximate)
Cooking and Food Preparation			
Range (standard)	12 500	100	$2 50
Range (self-cleaning cycle only)	3 200	4	0 10
Dishwasher	1 300	18	0 45
Oven-electronic	1 450	22	0 55
Kettle	1 500	12	0 30
Frying Pan	1 150	16	0 40
Broiler	1 400	0	0 25
Coffee maker	900	6	0 15
Hot Plate	1 320	8	0 20
Deep Fat Fryer	1 500	7	0 18
Barbeque Grill	1 350	5	0 13
Food Waste Disposer	450	3	0 08
Toaster	1 150	3	0 08
Grill (sandwich)	1 160	3	0 08
Waffle Iron	1 120	2	0 05
Carving Knife	90	1	0 03
Food Blender	390	1	0 03
Food Mixer	125	1	0 03
Can Opener	175	1	0 03
Mixer (hand)	100	2	0 05
Mixer (table)	125	2	0 05
Rotisserie	1 400	2	0 05
Home Entertainment			
Radio—tube type	50	8	0 20
Radio—solid state	5	1	0 03
Hi-fi—tube type	115	10	0 25
—solid state	30	6	0 15
Television (Black and White)	200	30	0 75
Television—colour	330	40	1 00
Comfort and Health			
Room Air Conditioner 6 350 kJ	935	60-400	1 50-10 00
Room Air Conditioner 9 500 kJ	1 400	90-600	2 25-15 00
Fan (portable)	115	4	0 10
Hair Dryer (portable)	350	3	0 08
Heat Lamp (infrared)	250	1	0 03
Heater (portable)	500-1 500	varies with wattage and use	—
Heating Pad	65	1	0 03

Appliance	Average Wattage	Monthly Kilowatt-hours (approximate)	Monthly* Cost (approximate)
Comfort and Health			
Humidifier (portable)	100	10	0 25
Shaver	15	1	0 03
Sun Lamp	280	1	0 03
Tooth Brush	10	1	0 03
Dehumidifier	350	15	0 38
Bed Blanket	180	10	0 25
Laundry			
Clothes Dryer	4 800	80	2 00
Iron (hand)	1 000	12	0 30
Clothes Washer (automatic)	500	8	0 20
Clothes Washer (non-automatic)	300	5	0 13
Water Heater (Cascade)	4 500	500	12 50
Food Preservation			
Food Freezer (430 m')	335	75	1 88
Food Freezer frost free (430 m')	425	90	2 25
Refrigerator-Freezer Non-frost free (340 m')	300	100	2 50
frost free (340 m')	500	150	3 75
Miscellaneous			
Clock	2	1	0 03
Power Saw	275	1	0 03
Floor Polisher	300	1	0 03
Lawn Mower	1 500	3	0 08
Sewing Machine	75	1	0 03
Vacuum Cleaner	800	4	0 10
Hedge Trimmer	125	1	0 03
Block Heater**	500	240	6 00
Drill	300	1	0 03
Furnace Fan Motor (oil or gas)	250	100	2 50
Oil Burner	260	50	1 25

*Based on an average cost of 2 5 cents per kilowatt hour which is continuously escalating
**Monthly kilowatt hours are based on a region with approx 3900°C annual total degree days (Southern coast of British Columbia Southern Ontario, coast of Nova Scotia)

Table 3 15.1-T_1
Average energy consumption for residential electric appliances [1]

3.15 Domestic Equipment and Appliances

A kilowatt-hour is one thousand watt hours It is the amount of energy consumed by an appliance rated at 1000 W operating for a period of one hour [2]

For example, a 9 500kJ 1400 W (1 4 kW) room air conditioner operating 24 h/d, uses 33 6 kW h of power At a power cost of $0 25/kW h, the daily cost of operation is $0 84

Tables showing typical wattages, monthly kilowatt-hour consumption, and monthly cost, are attached Data is given for most common domestic appliances

Such information should be provided to owners and occupiers of residential accommodation in order to increase awareness of consumption and monthly cost

For example

—non-automatic clothes-washer uses less energy than automatic type
—ordinary freezer uses less energy than frost-free
—ordinary refrigerator uses less energy than frost-free
—solid state radio uses less energy than tube-type

3.15.2
Other Constructional and Design Considerations

Where influence over choice of installation, location and type of appliance is possible, it should be exerted

3.15.2.1
Lighting

Fluorescent lighting is much more energy efficient than incandescent lighting 1-40 W cool white fluorescent lamp provides approximately 3200 lm of light, while one 100 W incandescent lamp provides 1740 lm

In addition, a fluorescent lamp is rated for 18 000 hours of life (at 3 hours per start) while an incandescent bulb is rated for 1000 hours

.1 **Dimmer:** Where the light for the dining room is provided by a ceiling mounted light, the installation of a dimmer will provide a variable level of illumination, a higher level for table setting and clean-up and a lower one for atmosphere and dining

3.15.2.2
Time Switch

Time switches provide accurate control of such devices as car engine heaters, security lights, heating and air conditioning equipment

For example, a car block heater need only be on for a period of 2 to 4 hours prior to use, rather than from late evening to early morning Heating and air conditioning equipment can be turned down when a residence is unoccupied for long periods of time during the day and during the night Night set back of space temperature is also possible

3.15.2.3
Photo Cell

Security lights can be turned on at dusk and off at dawn with a photocell control A combination photocell and time switch will turn lights on at dusk and off at a predetermined time.

3.15.2.4 Appliances

.1 **Microwave Ovens**[3]: Power savings can be as much as 50% to 75% compared with conventional electric ranges

Microwaves are a form of radiant, non-ionizing energy, similar to radio waves, sunlight, police radar and infrared heat Microwaves are NOT to be confused with the more common types of radiant, ionizing energies such as X-rays, and gamma and cosmic rays which can be dangerous to human tissue

Over-exposure to microwave energy can cause serious injuries However, stringent standards have been set by the Health Protection Branch, Health and Welfare Canada for testing microwave ovens, in order to protect the consumer against over-exposure

The oven automatically shuts off when the door is opened, and has a safety lock that will not allow the magnetron tube to produce microwave energy until the door is closed

The amount of electricity consumed would be similar to that used by an electric frypan

.2 **Appliance Location**: A refrigerator should be located away from direct warm spots, such as a stove oven, or heating outlet and not be placed opposite a window Free air should be allowed to circulate around sides and back of refrigerator.

.3 **Appliance Design**: Appropriate design and use of everyday materials could achieve useful reductions in energy consumption Manufacturers of appliances could perform a valuable service by instituting a labelling system giving positive advice on use for minimum energy consumption.

For example.

—Glass or ceramic dishes can be used with a 12°C lower oven setting because they transfer heat better than metal
—Flat-bottom utensils make firmer contact with surface elements and absorb heat more quickly
—Tight-fitting pot lids mean lower settings can be used
—Pressure cookers reduce cooking time
—Constant image T V consumes energy 24 hours per day.

.4 **Appliance Service**: Yearly service on items such as furnaces, air conditioners etc, can improve operating efficiency and reduce reduce operating costs.

3.16 Glossary of Mechanical Terms[1]

absorption: a process whereby a material extracts one or more substances present in an atmosphere or mixture of gases or liquids accompanied by the materials' physical and/or chemical changes

acceleration due to gravity: the rate of increase in velocity of a body falling freely in a vacuum. Its value varies with latitude and elevation. The International Standard taken at sea level and 45 degree latitude is 980.665 cm/s

accumulator: a storage chamber for low-side liquid refrigerant, also known as *surge drum* or *surge header*; also, a pressure vessel whose volume is used in a refrigerant circuit to reduce pulsation; also a pressure vessel connected to more than one circuit of a pneumatic system to obtain the average pressure of the connected circuits

adiabatic process: a thermodynamic process during which no heat is extracted from or added to the system

adsorbent: a material which has the ability to cause molecules of gases, liquids, or solids to adhere to its internal surfaces without changing the absorbent physically or chemically. Certain solid materials, such as silica gel and activated alumina, have this property

aeration: exposing a substance, or area, to air circulation

air, ambient: generally, the air surrounding an object

air, outside: external air, atmosphere exterior to refrigerated or conditioned space; ambient (surrounding) air

air, recirculated: return air passed through the conditioner before being resupplied to the conditioned space

air, reheating of: in an air conditioning system, the final step in treatment in the event the temperature is too low

air, saturated: moist air in which the partial pressure of water vapor equals the vapor pressure of water at the existing temperature. This occurs when dry air and saturated water vapour coexist at the same dry-bulb temperature

air, secondary: air for combustion supplied to the furnace to supplement the primary air

air, standard: dry air at a pressure of 760 mm Hg at 21°C temperature and with a specific volume of 0.833 m^3/kg

air change: introducing new, cleansed, or recirculated air to conditioned space measured by the number of complete changes per unit time

anemometer: an instrument for measuring the velocity of a fluid

approach: in an evaporative cooling device, the difference between the average temperature of the circulating water leaving the device and the average wet-bulb temperature of the entering air. In a conduction heat exchanger device, the temperature difference between the leaving treated fluid and the entering working fluid

aspect ratio: in air distribution outlets, the ratio of the length of the core of a grille, face, or register to width. In rectangular ducts, the ratio of width to depth.

blast heater: a set of heat transfer coils or sections used to heat air which is drawn or forced through it by a fan

blower: a fan used to force air under pressure

boiler, packaged: a boiler equipped and shipped complete with fuel burning equipment, mechanical draft equipment, automatic controls and accessories. Usually shipped in one or more major sections

chimney effect: the tendency of air or gas in a duct or other vertical passage to rise when heated due to its lower density in comparison with that of the surrounding air or gas; in buildings, the tendency toward displacement (caused by the difference in temperature) of internal heated air by unheated outside air due to the difference in density of outside and inside air

clo: a unit measuring the insulating effect of clothing on a human subject. 1 clo = 0.155 $(m^2 \cdot °C)/W$

coefficient of performance (heat pump): ratio of the rate of heat delivered to the rate of energy input, in consistent units, for a complete operating heat pump plant or some specific portion of that plant, under designated operating conditions

coil deck: insulated horizontal partition between refrigerated space and bunker

comfort chart: a chart showing effective temperatures with dry-bulb temperatures and humidities (and sometimes air motion), by which the effects of various air conditions on human comfort may be compared

3.16 Glossary of Mechanical Terms[1]

comfort line: a line on the comfort chart showing relation between the effective temperature and the percentage of adults feeling comfortable

comfort zone: *average*—the range of effective temperatures over which the majority (50% or more) of adults feels comfortable, *extreme*—the range of effective temperatures over which one or more adults feel comfortable.

condensate: liquid formed by condensation of a vapour In steam heating, water condensed from steam, in air conditioning, water extracted from air, as by condensation on the cooling coil of a refrigeration machine.

conduction, thermal: process of heat transfer through a material medium in which kinetic energy is transmitted by the particles of the material from particle to particle without gross displacement of the particles.

conductivity, thermal: time rate of heat flow through unit area and unit thickness of a homogeneous material under steady conditions when a unit temperature gradient is maintained in the direction perpendicular to area Materials are considered homogeneous when the value of the thermal conductivity is not affected by variation in thickness or in size of the sample within the range normally used in construction.

conduit: (1) a tube or pipe used for conveying fluid, (2) a tube or pipe in which wires may be enclosed for protection

connection in parallel: system whereby flow is divided among two or more channels from a common starting point or header

control, dual effect: one responsive to temperatures of two zones or to two variable conditions

cooling, evaporative: involves adiabatic heat exchange between air and a water spray or wetted surface The water assumes the wet-bulb temperature of the air, which remains constant during its traverse of the exchanger

cryogenics: a study of the production of very low temperatures and their effect on the properties of matter

damper, barometric: a device that controls draft by a balanced damper which bleeds air into the breeching on changes of pressure to maintain a steady draft

damper, multiple louver: a damper having a number of adjustable blades

decibel: a unit used in acoustics for expressing the relation between two amounts of power By definition, the difference in decibels between two powers (P_1 and P_2), P_2 being the larger, is: db difference = $10 \log_{10} P_2/P_1$.

declination of sun: the angle above or below the equatorial plane. It is plus if north of the plane and minus if below. Celestial objects are located by declination

degree day: a unit, based on temperature difference and time, used in estimating fuel consumption and specifying nominal heating load of a building in winter For any one day, when the mean temperature is less than 18 3°C, there are as many degree days as degree Celsius difference in temperature between the mean temperature for the day and 18 3°C

design working pressure: maximum allowable working pressure for which a specific part of a system is designed

dew point temperature: the temperature at which condensation of water vapour in a space begins for a given state of humidity and pressure as the vapour temperature is reduced; the temperature corresponding to saturation (100% relative humidity) for a given absolute humidity at constant pressure

dielectric: an insulator

differential: of a control, difference between cut-in and cut-out temperatures or pressures.

diffuser, air: a circular, square, or rectangular air distribution outlet, generally located in the ceiling and comprised of deflecting members discharging supply air in various directions and planes and arranged to promote mixing of primary air with secondary room air.

direct connected: driver and driven, as motor and compressor, positively connected in line to operate at same speed

energy, available: the portion of the total energy which can be converted to work in a perfect engine.

enthalpy: a thermodynamic property of a substance defined as the sum of its internal energy plus the quantity *Pv/J; where P* = pressure of the substance, *v* = its volume, and *J* = the mechanical equivalent of heat; formerly called **total heat and heat content.**

3.16 Glossary of Mechanical Terms[1]

evaporator (refrigerant): a heat exchanger in which liquid refrigerant, after reducing its pressure (expansion), is evaporated by absorbing heat from the medium to be cooled

fan, centrifugal: a fan rotor or wheel within a scroll-type housing and including driving mechanism supports for either belt drive or direct connection

fan, tubeaxial. a propeller or disc-type wheel within a cylinder and including driving mechanism supports for either belt drive or direct connection

fan, vaneaxial· a disc-type wheel within a cylinder, a set of air guide vanes located either before or after the wheel, and including driving mechanism supports either for belt drive or direct connection

heat, latent· change of enthalpy during a change of state, usually expressed in J/kg With pure substances, latent heat is absorbed or rejected at constant temperature at any pressure

heat, latent, of condensation or evaporation (specific)· thermodynamically difference in the specific enthalpies of a pure condensable fluid between its dry saturated vapour state and its saturated (not subcooled) liquid state at the same pressure

heat exchanger: a device specifically designed to transfer heat between two physically separated fluids

heat exchanger, heat pipe: a bundle of separate tubes each containing a two-phase working fluid A heat source at one end evaporates the fluid, the gas is then condensed by a heat sink at the other end The liquid is returned by gravity or by wick capillary action to the tube's heated portion

heat exchanger, plate· fixed plates which segment and keep separate the hot and cold fluids

heat exchanger, rotary: a cylindrical wheel or drum packed with fluid conducting heat transfer medium which is rotated through one fluid and then through a counter-flowing second fluid

heat exchanger, run-around: finned tube coils (closed system) or spray chambers (open system) in which a liquid is circulated by gravity or pump action through a heat source and then through a heat sink Antifreeze may be used in the coil loop, and a desiccant, in the spray system

heat pump, cooling and heating a refrigerating system designed to utilize alternately or simultaneously the heat extracted at a low temperature and the heat rejected at a higher temperature for cooling and heating functions respectively

hot gas line: a line used to convey discharge gas from the compressor to the evaporator for defrosting

humidistat: a regulatory device, actuated by changes in humidity, used for automatic control of relative humidity

humidity, percentage: the ratio of the specific humidity of humid air to that of saturated air at the same temperature and pressure, usually expressed as a percentage (degree of saturation, saturation ratio)

humidity, relative: the ratio of the mol fraction of water vapour present in the air to the mol fraction of water vapour present in saturated air at the same temperature and barometric pressure Approximately, it equals the ratio of the partial pressure or density of the water vapour in the air to the saturation pressure or density, respectively, of water vapour at the same temperature

joint, mechanical: a gas-tight joint obtained by joining of metal parts through a positive holding mechanical construction (such as flanged joint, screwed joint, flared joint)

manometer: an instrument for measuring pressures, essentially a U-tube partially filled with a liquid, usually water, mercury, or a light oil, so constructed that the amount of displacement of the liquid indicates the pressure being exerted on the instrument

outlet, vaned: a register, or grill, equipped with vertical and/or horizontal adjustable vanes

phase: (1) in thermodynamics, one of the states of matter, as solid, liquid, or gaseous, (2) electrically, an alternating current whose alternations have a definite time relation to the rotational position of the alternator.

pond, spray: arrangement for lowering the temperature of water in contact with outside air by evaporative cooling of the water The water to be cooled is sprayed by nozzles into the space above a body of previously cooled water and allowed to fall by gravity into it.

3.16 Glossary of Mechanical Terms[1]

potentiometer: an instrument for comparing small electromotive forces or for measuring small electromotive forces by comparing a known electromotive force Its principal advantage is during measurement, no current flows through the source of electromotive force

radiation, thermal: transmission of heat through space by wave motion; passage of heat from one object to another without warming the space between

resistance, thermal: the reciprocal of *conductance, thermal*

resistivity, thermal: the reciprocal of *conductivity, thermal*

shell and tube· pertaining to heat exchangers in which a nest of tubes or pipes, or a coil of tube or pipe, is contained in a shell or container. The pipe (or pipes) carries a fluid through it, while the shell is also provided with an inlet and outlet for fluid flow

solar constant: the solar radiation intensity incident on a surface normal to the sun's rays outside the earth's atmosphere at a distance from the sun equal to the mean distance between the earth and the sun Its value is 1 353 W/m^2

system, central fan: a mechanical indirect system of heating, ventilating, or air conditioning, in which the air is treated or handled by equipment located outside the rooms served, usually at a central location, and conveyed to and from the rooms by a fan and a system of distributing ducts

system, central plant: a system with two or more low sides connected to a single, central high side, a multiple system

system, closed: a heating or refrigerating piping system in which circulating water or brine is completely enclosed, under pressure above atmospheric, and shut off from the atmosphere except for an expansion tank

system, off-peak· a system with control which normally avoids use of power during peak load periods, usually having eutectic or water-ice hold-over means

system, one-pipe. a piping system in which the fluid withdrawn from the supply main passes through a heating or cooling unit and returns to the same supply main

system, open: a heating or refrigerating piping system in which circulating water or brine return main is connected to an open-vented elevated tank which serves as a reservoir to accommodate expansion and contraction of the fluid, and as an inspection point for the fluid's condition

system, run-around: a regenerative-type closed secondary system in which a continuously circulated fluid abstracts heat from the primary system fluid at one place, returning this heat to the primary system fluid at another place

system, two-pipe: a piping system in which the fluid withdrawn from the supply can passes through a heating or cooling unit to a separate return main

transmittance, thermal (*U* factor): the time rate of heat flow per unit area under steady conditions from the fluid on the warm side of a barrier to the fluid on the cold side, per unit temperature difference between the two fluids

ventilation: the process of supplying or removing air by natural or mechanical means to or from any space. Such air may or may not have been conditioned

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4.0 Design Criteria for New Construction

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4.8 Doors and Windows

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4.9 Protective Elements

4.9.1 Screens, Blinds, Shutters, Canopies — John Hix, M Arch , M A , MRAIC

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4.1 Building and Site Characteristics

4.1.1 Site Characteristics

Many modern buildings have ignored their sites. Stated more correctly, the designers of these buildings have not considered the ecology, existing landforms, climate or environmental factors such as wind, sun, precipitation and temperature range. They have ignored the daily and seasonal changes. They have also ignored the micro-climate created by other buildings adjacent to their own location and the unique situations created by interaction of adjacent buildings with the existing landscape.

4.1.1.1 Independent Buildings

In the recent past, buildings could remain independent of their sites because vast amounts of energy were available to operate the mechanical systems needed to compensate for the lack of harmony between building and location Massive mechanical intervention usually results when conditions of the site are grossly unfavourable to the efficiency and comfortable operation of the building Further, more mechanical effort than necessary can be extended when a building simply does not take advantage of the site's favourable qualities

4.1.1.2 Adaptation

What characteristics does the site have both favourable and unfavourable that can effectively be utilized or avoided in terms of the building's energy efficient design?

Much has been written about the traditional ways in which buildings have been adapted to site It is instructive to note how, in the past, diverse and distinctive architectural expression evolved in response to local and regional influences.[1] In contrast, the uniform solutions of the International Style in recent years generally made only slight acknowledgement of differences in location or climate.

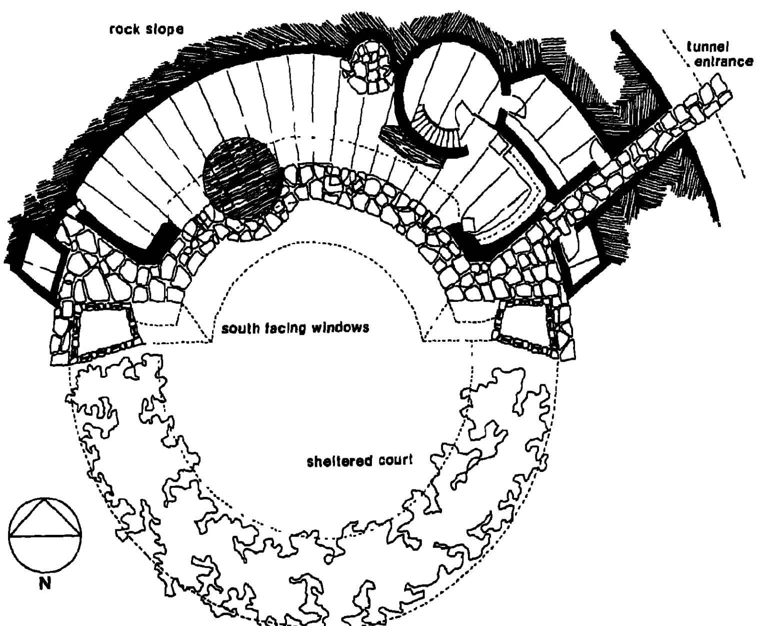

Figure 4.1 1.2-1
'Solar hemicycle' house, Wisconsin Frank Lloyd Wright, architect.

There were exceptions which were more energy conserving and among these are the residential buildings of Frank Lloyd Wright[2]. Harmony with the site was their starting point and, even though energy conservation was not a priority, they are much more oriented towards this than the work of most of his contemporaries

4.1.1.3 Wind

By controlling the air pressure differences around the building perimeter, natural ventilation can be increased and air infiltration lessened Further, self-orienting wind catchers can be designed to catch and manipulate wind for ventilation If the building can use it and the site can offer it, wind generated power is also a possibility

4.1.1.4 Water

The effect of topography and ground cover on climate was covered in detail in **Section 2 1** and it was noted how proximity to water modifies local air temperature and climate Water bodies are excellent sources of atmospheric moisture Obviously, this can greatly affect the humidity factors involved in the calculation of the energy efficiencies of a particular building Locations adjacent to lakes are influenced not only by prevailing winds but by land-lake breezes These breezes occur whenever there are differences in the air temperature over the land and over the water—on these occasions the colder air moves toward the warmer

Water absorbs heat from the air which crosses it and can also give off this heat when the surrounding environment is cooler Because of this, areas adjacent to large bodies of water have diurnal and seasonal temperature regimes related to the water temperature

On a smaller scale, water heat storage can be utilized on a daily basis for individual buildings The reflection of sunlight off water should be noted and compensations made Water can be used in the cooling of a building, whether supplying fountains or the building's mechanical system

4.1.1.5 Existing Landscape

Existing landscape can act to moderate the micro-climate of the area by blocking wind, cutting direct or reflected solar radiation and by increasing or lowering the temperature in relation to the general area Factors that work well in one season, such as a grove of trees blocking winds or shading of buildings, do not necessarily work well in other seasons If the temperature range on the site is useful, warm days and cool nights lend themselves to a building that can open and close taking advantage of this cycle Water heat storage can be part of this.

Using this earlier example, depending on type of tree planted, the grove could also prevent natural ventilation and cooling by the prevailing winds or natural heating by the sun

4.1.1.6 Sun

Generally, east-west sun is more difficult to deal with than southern light A rectangular building should be oriented, generally speaking, with its long axis running east-west. West sun can bring about the most intense solar gains and is the most difficult to control Again, the changes in sun exposure brought about by the seasons and the time of day should be fully described for each site. What is advantageous in one season, or one time of day, could be a disadvantage in another

In suburban and urban sites, there are additional factors to consider Special situations are brought about by existing buildings on or near the site and sun patterns may become very complicated. Depending on the time of day and season, solar radiation can be both intensified by reflection off an adjacent building or completely blocked by it. The amount of solar radiation it receives, therefore, is not necessarily what it would be on an open site. The pattern is not a constant one as each new building can bring with it new environmental conditions

4.1.1.7 Prime Functions of the Building in Relation to the Site

What general characteristics does the building have that can be adapted to the site to increase its energy conservation potential?

Each site, as discussed in Section 4.1, has particular features, some of greater prominence or more overriding concern than others. With a set of requirements in mind and prime functions of the building clearly understood, their matching with particular site characteristics can commence.

4.2 Requirements of a Structural System and Building

4.2.1 Structure

Within proper safety standards, careful consideration of structural design can reduce the size and general amount of structural material needed. This will conserve energy not only in the original production of those structural components but in their transportation, erection and site assemblage. Advances in building techniques allowing faster and simpler assembly also aid better energy conservation. A secondary gain to be derived from economy in the structural system will be the greater net volume obtained in relation to the gross volume of the building constructed.

4.2.1.1 Integration of Structural Mechanical Systems

The appropriate integration of structural and mechanical systems is an essential requirement for energy conservation. In assessing the design it is the net amount of material involved which must be considered. For instance, the savings in structure might increase the complexity of the ventilation system. Also some energy conservation techniques require relatively more structure in order to support berms, sod or ponded roofs.

When included in an exterior wall, structural columns and spandrel beams permit undesirable heat transfer between inside and outside of the building. 'Through the wall' structural members should be avoided. If this is not possible they should be insulated and a thermal break included. (Ref. Section 3.1.4).

4.2.2 Building Elements

Examined under this heading are exterior and interior walls, openings (windows and doors), roofs and floors.

4.2.2.1 Exterior Walls

One important function of exterior walls is to retard heat flow and to control air passage from the exterior to the interior (or vice versa). Their design can greatly affect the building's overall efficiency and there are many factors involved. For instance, keeping the interior portion of the exterior wall mass as large as practical and using the appropriate amount of insulation on the exterior side will have beneficial effects on both the heating and cooling. A detailed analysis of the thermal storage characteristics of building structures and the potential for energy conservation was presented earlier in Section 3.1.5.

Exterior walls should be designed to be continuous at points where they meet interior partitions. Thermal chimneys or vented walls are useful in buildings in which the cooling requirements are a predominating concern. Walls constructed in this manner are double-skinned and permit warm air to rise and pass upwards between interior and exterior walls. Such a system has been used traditionally in warm climates. This system, if adjusted, can also allow the relief of internal air pressure variations arising from temperature changes without damage to the wall.

Construction supervision is important in all cases to make sure that energy efficient components are properly built and installed and that they are functioning to specifications In this regard, the construction sequence should be planned to avoid cracks and temporary joints through the wall. Also, walls might be detailed such that the insulation and construction can be checked during the life of the building and changed if needed

4.2.2.2 Interior Walls

Interior walls should not be left unconsidered. Insulation is necessary in these locations when specific building uses generate or require an environment that is not compatible with that of the remainder of the building. It is much simpler and more energy efficient to isolate such building segments and respond to their particular energy needs without allowing the entire building to be affected The entire energy system is not then required to respond to what might only be a small part of the building's operation. It should be noted again that sometimes the specific environmental qualities in the appropriate season become useful. For instance, heat generation from a machinery room during winter.

4.2.2.3 Openings

Windows and doors present special problems Even triple-glazing can allow greater heat gain and loss and air infiltration than most exterior wall construction (Ref. Section 4.8). For that reason, exterior shading devices or solid shutters which can be closed to decrease thermal transmission, work well in association with glazing The efficient thermal performance of exterior shuttering must be weighed against increased maintenance problems in comparison with interior devices

Solar orientation is important as well as horizontal and vertical angling in the wall or glazing. Windows, for instance, positioned high in a wall increase reflection on the ceiling of a room and reduce glare. Window quality in terms of energy conservation should be tested and installation must be of the highest standard in order to gain full benefit. If skylights are used, they should be double or triple glazed

Doors can be sources of large amounts of both air and heat exfiltration. They should have close to the same insulation properties as walls and their closures should be secure. Again, the building design should protect these openings with airlocks such as vestibules or revolving doors. Weatherstripping should be adjustable to compensate for door warpage and shrinkage of materials. Generally, since no door or opening can be totally sealed, reduction of the total number in a building will promote energy efficiency.

4.2.2.4 Roofs

Roofs are yet another component of the building fabric which can be dealt with in an energy efficient manner. The amount of roof area depends on the form of the building chosen. This allows for its use as a planning option in designing energy efficient buildings. For instance, a building with a sloping roof facing south will be subjected to intense solar radiation. A flat roof under certain con-

ditions can benefit from the additional seasonal insulation afforded by snow cover

Insulation in the roof, obviously, is essential and there are many different ways to achieve the desired standard A roof could utilize a pond, sod and planting, a spray, rooftop equipment rooms, a double skin with ventilation space between, increased thermal capacity and wind-deflection devices

Light colours for roofing material are helpful in reducing the solar heat gain If this is a major concern that must be dealt with to obtain energy efficiency in a building, shading of the roof could be very important There are many ways this can be done For example by planting which can shade the roof, by erecting a high parapet wall that casts shadows on it or by angling the building so that, in fact, it becomes self-shading It should also be noted that a rough texture on external surfaces increases the value of their film coefficient.

4.2.2.5 Floors

Floors also can be important elements in terms of energy conservation, particularly exposed floor areas Buildings on columns or with large overhangs which expose the underside of large areas of floor area will use proportionately more energy than buildings that do not have surfaces exposed in this manner Open structures such as garages, do not have to be heated or insulated, but the adjoining floor areas to these spaces when part of a building must be insulated Unheated areas of this nature are sometimes treated as if they are in fact heated or enclosed and improper insulation provided between the floors is the cause of considerable heat loss Additional protection of these secondary areas can be provided by earthworks or landscaping.

4.3 Building Form, Geometry, Surface, Volume and Usable Area

4.3.1 Above-ground Construction

The following discusses in general terms the relationship between building form and energy conservation. The reader is also referred to Section 4.4 General Criteria for Energy Efficient Design which examines specific categories of buildings.

4.3.1.1 Compact Shape

A compact building shape as close to a cube as possible is the ideal shape in terms of energy efficiency for a building Ref Figure 4.3.1.1-1.

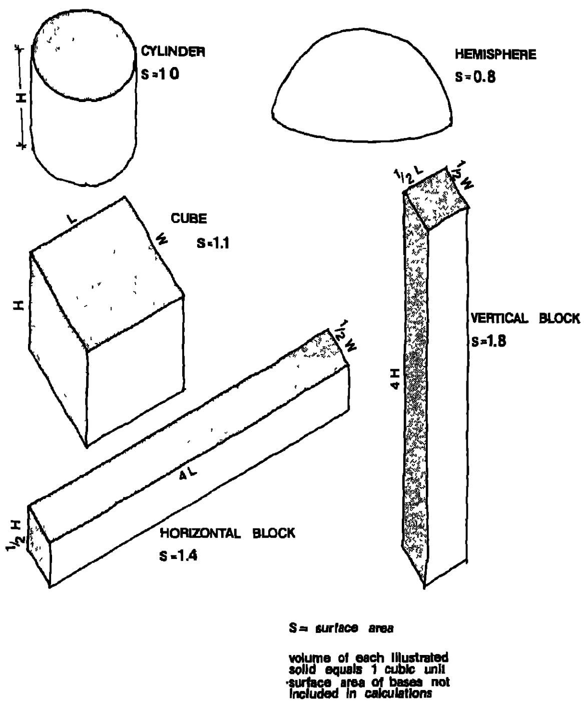

Figure 4 3 1.1-1
Volume and surface area relationships [1]

4.3.1.2 Perimeter

Since heat can escape through exterior walls in the winter and be absorbed by them in the summer, the heating and cooling of a building are affected by the amount of exposed wall area. The same is true of the roof. Therefore, a building that encloses the largest volume for the least perimeter surface area including roof will be the most likely to be energy efficient.

4.3.1.3
Ceiling Height

A major factor in determining the exterior surface area is the floor to ceiling height of a building Although other factors in energy conservation usually determine this dimension, it should be noted that lower ceilings have many advantages in terms of energy conservation. High ceilings allow warm air to rise and cool air to come in underneath This can be beneficial in warm months. However, a lower ceiling decreases the amount of exterior surface for the usable square footage enclosed. With lower ceiling heights, smaller windows can be used and lighting fixtures can be operated more effectively and efficiently

All three factors combine to give greater energy efficiency in a building.

4.3.1.4
Compact Massing

A compact massing is a desirable characteristic Although a tall building has less exposed roof proportionately, it is not as efficient in terms of volume achieved to perimeter area It is also a form which is subjected to greater wind which increases air infiltration and heat losses and it is a structure not as likely to be protected by existing buildings or landscape These buildings also require more mechanical systems, elevators, more extensive duct systems and special mechanical systems to deal with the sir infiltration caused by the stack induction action typical in tall buildings

Sprawling single-storey buildings are not good either in terms of their enclosed volume to perimeter surface ratio This is not only because of their exposed wall area but because of their proportionately larger roof surfaces Additionally, utility and mechanical systems cannot be stacked in this type of building and extensive duct systems are needed The resulting inefficiency produces both higher initial cost of installation and greater operating costs However, it should be noted that this type of building can take advantage of a site characteristic to a greater degree than a more compact building

4.3.1.5
Building Forms

Within the concept of a compact building shape, many building forms can be utilized, depending on the particular requirements. For example, where exposed perimeter wall area is not seen as an overriding concern in a particular situation and cooling is of the greatest importance, a dome can be used (The dome has the least surface area for volume, but it is not always a usable volume) This form allows warm air to rise and collect at the top The heated air can be expelled through a vent and cooler air drawn into the space

Buildings whose forms shade themselves should also be considered. Horizontal and vertical sloping walls can be used to control the impact of solar radiation. East and west walls that are serrated on plan provide summer sun shading while permitting low angle winter sun into the building through the windows with southern exposures. Indentations in this way also provide wind breaks which help to prevent air infiltration. Additionally, in buildings with particularly large enclosed volume for the amount of perimeter surface area, they can provide natural light and views into floor areas which would not normally receive them.

However, the advantage of this along with other building configurations which may be suitable for a particular site must be assessed in regard to the amount of exposed perimeter wall surface relative to the volume or area enclosed

Pyramidically shaped buildings have forms that could be used to take advantage of top lighting if properly oriented.

Rectangular buildings with small serrations on the perimeter could effectively screen out heat gain while allowing natural light and view by the orientation of glazing to the desired direction This would be very advantageous particularly in more regularly shaped buildings that enclose spaces more economically than those formed with large-size indentations

4.3.1.6 Courtyard-type Buildings

One of the best building forms for energy efficiency is the courtyard-type building which permits a large area to be enclosed with a minimum amount of perimeter wall The central enclosed roofed courtyard area or areas provide the visual interest for those in the building who are at a distance from the exterior view Considering some building sites, the courtyard orientation might even be a preferable one. Since there would be relatively little energy loss through the windows or openings on the courtyard side, there can be considerably more glass or openings here. The courtyard itself could be naturally lit with skylights, wall-glazing or a well-insulated clerestory If solar heat gain is required, passive collection from south facing windows (protected from summer sun) is possible There are many interesting design possibilities with this energy efficient form.

4.3.2 Underground Construction

Underground construction can be extremely energy efficient and, if designed in an appropriate manner, can create very pleasant places for a wide range of activities.

4.3.2.1 Application

The main advantage of underground construction is the benefit of the insulating property of the earth, including reduction of wind-chill factor and its levelling out of the requirements for heating and cooling. In the winter, with an appropriate roof, the snow would complete this natural insulation shell Many types of roof surfaces are possible such as sod or pond. A pond roof could be used in a building ventilation system also. Offsetting these natural advantages would be the increased effort needed for natural ventilation, condensation control, natural light and, depending on the situation, view and outside orientation.

4.3.2.2 Partially Underground Construction

To utilize the benefits of underground construction, a building need not be totally in the ground Two or three sides could be buried in a hillside while the third or fourth opens on grade or has open areas for windows. This form could be used with a top lighted

interior court space to provide comfortable areas for those farthest from the exposed side or sides.

4.3.2.3 Skylighting

Skylighting and top lighting of various types could be very important in an underground construction, they must be considered in a similar fashion to regular glazing That is, depending on the orientation, they will allow the same amount of solar radiation in and a similar amount of heat to escape Double and triple-glazing and screening, moveable or fixed, should be considered If screening is to be used, it should be on the outside of the building to be of the greatest use. It is common practice to assume that ordinary skylighting is energy efficient lighting, but it is skylights that, being on the roof, are most usually continuously exposed Clerestory or alternatively, directional skylighting, is generally preferable as the orientation of light can better be anticipated and appropriately dealt with. If a building were totally in the ground with only the roof area exposed, top lighting would almost always be necessary to create pleasant space This could be created so that the exterior portion of it would be integrated attractively into the above grade landscaping or open spaces

Inside, top lighting would permit the dramatic use of plant material, reflective surfaces, volumes, and finishes that respond to sun and shadow and are enhanced by this kind of lighting

The screening devices used on the exterior and interior also become, as with the sources of the light, handsome architectural features of both the inside and outside spaces.

4.3.2.4 Underground Components

Underground construction might also be considered with above ground buildings For example, in a shopping mall, although entries are on grade, a portion of the enclosed area is frequently underground and connected to the above ground portion in such a manner so that one is not really aware of the transition to below grade levels The same could be true for portions of office and residential buildings.

It is unnecessary for many buildings with strictly mechanical or storage functions to be above ground structures Some of these functions could easily be housed in below grade buildings When accommodated in a building with above ground orientation such functions should, as much as possible, still utilize below grade placement.

4.4 General Criteria for Energy Efficient Design

4.4.1 Introduction

Although it would relieve the architect of the responsibility to think out each problem in light of its own particular characteristics, energy efficiency cannot be described in terms of a check list Each building design has its own set of criteria and relationships between these that must be considered One can discuss in a general fashion concepts that can promote energy efficiency and particular ways in which they could be implemented. However, it is impossible to describe an ideal situation for energy conservation for any building General principles and specific technical solutions and approaches must be applied by the architect to each individual situation Only in this way can energy conserving systems be developed which meet particular requirements and which are appropriate for their location The following criteria for energy efficient design are offered with the foregoing comments in mind.

For the architect, the most important design considerations relating to the energy efficiency of a building are the ones associated with 'Passive Conservation' techniques. Naturally, there should also be an awareness of the mechanical advances in the field so that these can be utilized and incorporated into the building's design In certain situations the building might have to be designed around the mechanical necessities

An architect must not try to remedy the lack of energy efficiency in a building by assuming that its engineering components will take care of it Energy efficiency is not something that is imposed on a building and achieved solely by mechanical means but something that originates with the basic design decisions made for the building Most of these decisions can find form within standard building techniques

Architects should not depend on engineers to do the work for them It is equally important that they work with qualified engineers from the commencement of design so that the building can take full advantage of energy conservation technology Passive and active energy conservation techniques should work harmoniously Specific requirements should generate appropriate technology and the various solutions assembled by the architect and engineer to form an efficient and economical system.

4.4.1.1 Building

The importance of the shape and construction of the building, as well as its siting, to energy conservation has been discussed in preceding **Section 4.1.2.**

4.4.1.2 Interior Arrangement

The interior arrangement of spaces comprises another general category that must be considered in relation to energy efficient building design Components of a building should be arranged to take advantage of site characteristics depending on their energy requirements. Their relation to each other should take advantage of their mutual characteristics. Further, the components in the building as a whole can, through both these arrangements, come to a balance which assists energy efficiency.

The interiors of a building should capitalize on design decisions which are made for energy reasons. They should utilize the different forms, room arrangements, organization, or lighting to their advantage to create unique and pleasant environments.

4.4.1.3 Technology

Another general category is one of awareness of technology Most passive means of energy conservation can be achieved through regular building construction. However, advances in materials and methods occur rapidly. This is especially true as energy conservation becomes increasingly important. The consequences of approaching building design with energy conservation as a priority should be recognized The architect must be prepared to strike out in new directions. A fixed idea of what a building is to be or an inflexible attachment to aesthetic images can only be detrimental to the end result. Again, the importance of a good working relationship with knowledgeable engineering consultants during the design stage cannot be stressed too strongly

4.4.1.4 Balance

Underlying all these broad guidelines is the question of balance in the decisions the architect must make, the weighing of advantages and disadvantages, whether concerning a particular site or alternative means of energy conservation. But the most important balance to be struck is the one between the anticipated results when energy efficiency is used as a major priority in decision making and the ideal conditions the building should create Implied in the latter is the optimization of environmental quality for those who use the building either in terms of urban design, or in terms of the architect's aesthetic sense of the way things should be For example, a cubed shaped building utilizing large floor areas with few or no windows and partially, if not totally, in the ground could be extremely energy efficient but it could also cause some as yet not fully understood problems both for its user and others

This is not to suggest that energy conservation is at odds with the optimization of the quality of the environment for people or for any of the other categories noted It is suggested, however, that no set of energy efficient guidelines can be applied arbitrarily to a building without the most basic reconsideration of its design

Sometimes the most energy efficient approach in a specific area is not the one that in the long term will produce a pleasant working environment and hence an efficient and profitable one On the other hand, there are also energy conservation techniques which offer immediate advantages in terms of environment as well as long term economic benefits

A good design will take advantage of the requirements for energy efficiency and make something of them that is better than would have been without this priority. A poor design will usually result when energy conservation guidelines are simply applied to a standard building without any basic change in design philosophy When new priorities are not synthesized in an innovative way, a building ends up with a great number of excuses for the way it is produced

The most successful buildings, considerately designed for energy conservation, have gone past the obvious implications of mandatory requirements to realize a radically new creativity In these buildings their designers have set the highest and most difficult standards for themselves, both in terms of energy conservation and design.

4.4.2 Residential Construction

Residential buildings can offer great innovative possibilities for the application of energy efficient techniques Until recently, the most widely held concept of energy conserving building has been based upon widely publicized and imaginative house designs utilizing renewable energy resources

In particular, houses incorporating active solar energy systems have attracted a great deal of attention However, a house using active solar heating techniques is not necessarily an energy efficient one This house could, in fact, be grossly inefficient from this viewpoint and merely be using solar energy equipment to compensate for its inadequacies The use of solar energy in general can be an important part of an energy efficient dwelling But much can be done passively as well as actively, depending, of course, on the individual circumstances

General principles relating to siting and building form have been discussed previously and apply here

4.4.2.1 Siting

The careful use of the site can have its most dramatic results with residential building A house in a natural setting can respond to the advantages of the site and its micro-climate to achieve good energy efficiency most readily This aspect of design has been covered in previous sections (Sections 2.1 Climate and 4.1 Building and Site Characteristics) and there is no need to repeat here.

In addition there are numerous published case studies that give details of what this means in a practical sense

4.4.2.2 Perimeter

The volume enclosed in relation to the exposed building surface, as mentioned in Section 4.3 Building Form, must always be considered The importance of glazing in the total system should be noted With the proper screening (Ref Protective Elements, Section 4 9) the benefit of heat gain can be utilized at appropriate times and avoided at others Glazing should have at least the recommended *RSI* value Shutters, open during the day and closed at night, and other insulating devices should be considered to augment this insulation value Berms and sod roofs and other forms of natural insulation, including provision in the winter for snow insulation on the roof, should be utilized if possible The absorptive or reflective properties of house finish materials and ground cover planting can assist in the control of building heat loss or gain

Garages, and to some extent closet spaces, can be used as buffer zones between areas that are either to be heated or air conditioned and between the exterior and interior.

Grouping of such spaces can form buffer zones on a larger scale in housing development

4.4.2.3 Greenhouses, Fireplaces, Swimming Pools

Greenhouses, fireplaces, swimming pools, and vestibules can all be components that help provide greater energy efficiency in a residential building.

.1 **Greenhouses:** Greenhouses can generate heat in the winter (Section 3.10.1). They can be opened out to the outside, externalized, or screened during specific times to allow solar gain to be dissipated in the environment rather than in the dwelling when appropriate More than likely this will be in the summer months Greenhouses can also be used to regulate internal humidification As a design feature they are useful in providing what can be a self contained and extensively glazed area In the summer, living space can be extended outside while in the winter, the greenhouse can serve this function

.2 **Fireplaces:** Fireplaces can generate a substantial amount of heat with the incorporation of new fireplace technology They should be centrally located in dwellings When a proper air flow system based on convection heating, is installed, a fireplace takes cool air in, heats it, and expels it into a room For a given amount of fuel more heat can be transmitted by the convection currents generated in the room in this way than by the minimal radiant transmission from a fireplace Water tanks adjacent to the fireplace will act as thermal reservoirs and provide useful heat when the fire is no longer burning Solar heating can be utilized in a similar manner, also

A heating ventilation system that brings fresh air directly in from the outside to the fireplace, heats it, and then circulates this air, circumvents the use of the oxygen in an environment It also helps to eliminate drafts and the removal of warm air from inside the house.

Heat must be stopped from 'going up the chimney' and a tank system could be utilized in the upper floors that takes heat from the flue and distributes it to the upper levels Dampers are required in flues and doors should be provided for those periods when the fireplace is not in use Fireplaces incorporating waste disposal systems are especially efficient

.3 **Swimming pools:** Swimming pools can be incorporated into a building's energy system, both passively and actively Orienting a pool with the wind direction could lower the temperature of the wind Using a pool as part of a mechanical heating or cooling system is also a possibility as it can be used to dissipate or store heat Interior pools might be used in similar ways In this situation they can especially influence the humidity level of a building

(Root cellars and cold rooms in basements are also useful ways of avoiding expensive cooling and refrigeration systems)

4.4.2.4 Vestibules

Vestibules and entries should be considered very carefully in residential work as doorways make up a substantially greater percentage of the wall space in residential construction than in any other type of building Doorways should be protected from wind during winter and conversely open to sunlight and ventilation in summer. In winter, a double door system should be considered to keep as much heat in the building as possible. To construct elaborate means for gathering heat in the winter and to waste it through insubstantial insulation, or an entry that permits a large amount of air infiltration, is not sensible. The construction of doorway and window openings should be made as airtight as possible (Ref. **Section** 4.2.2.3 Openings).

4.4.2.5
Solar Energy

Solar radiation can be used to provide energy for a house or groups of houses with shared systems The economy of such installation must be considered carefully for each individual situation to conserve energy passively and the life cycle costing of the systems being considered are two such considerations An existing building may need special modifications to permit the implementation and maintenance of a solar energy system Every possible means of passive energy conservation should be applied before still unperfected technology is adopted for any situation

4.4.2.6
Standard of Comfort

The standard of comfort desired must be examined as ultimately it is the basis for determining the means that will be utilized to encourage an energy efficient environment

If we insist on a high standard temperature in the winter and a very low one in the summer, both passive and active energy conservation methods will be strained However, if we learn to adapt to slightly cooler winter temperatures (possibly by just wearing a sweater), and warmer summer temperatures by allowing the home to open to shaded areas or utilize fountains and natural breezes, energy supply can be conserved more easily More so than any other type of building, a house can truly be a 'machine for living' in the best sense

If we can learn to accept a reasonable standard of environment and begin to take the responsibility for manipulating it (be it the closing of shutters in the evening for insulation or the efficient running of mechanical devices), the greatest energy savings can then be realized The simplicity of just turning a dial will have to be replaced with the responsibility of planning effectively, being aware of technological improvements and utilizing manually operated devices that can manipulate the wind or provide solar control A house that can open up to and close off the environment, use it to its advantage and protect itself from environmental inclemency, when necessary, is the goal to be achieved. Those responsible for their own environment can be the source of the greatest innovation

The appearance of an energy efficient house might be different than an individual's expectation of his or her ideal home. This must be considered However, architects should be able to design energy effective houses which incorporate conservation devices but still reflect the traditional vernacular of the region or that desired by an individual A house, as architect John Hix has said, is not just an expression of a heating system However, some modification in appearance is something which is to be expected for the benefits a person is receiving from energy efficiency.

4.4.3 Educational Buildings

Improved energy efficiency in educational buildings suggests not only construction efficiencies and the more complete utilization of existing facilities (including possible retrofitting) but a more basic change in the concept of how education facilities should appear.

4.4 General Criteria for Energy Efficient Design

4.4.3.1 Use

Most educational facilities, even those of appropriate construction, would be more energy efficient if they were used more That is if their daily schedule were more inclusive, Night School, after school use of the athletic facilities, etc , could be introduced and their yearly schedule extended for Summer School The energy cost per person would then be lower When planning an educational facility the energy saving to be made in this way should not be overlooked Buildings should be designed with the 'full use capability That is, the components of a building that are readily usable by the community at large should be made as identifiable and accessible as possible so as to facilitate this use Also, an extended operating day and year permit the use of many mechanical advances in energy conservation not possible in a building only operating for short periods and irregularly

4.4.3.2 Compact Shape

Education facilities, public schools in particular, are not usually compact in shape. The single or double-storey sprawl should be avoided A three-storey double-loaded system needs 35% less building surface than a single-storey building This brings about obvious energy efficiency Again, the principle of most enclosed volume per least exposed wall perimeter should be utilized

An educational building usually provides many program requirements such as gymnasium, auditorium, library stacks, change rooms and hallways, which need not have any exposed wall area Additionally, in training areas, kitchen, etc , although natural light may be desirable, there is not necessarily a need for outside windows These factors can all be utilized to help improve the ratio of enclosed volume per exposed wall area and to lessen the openings in a building's fabric

4.4.3.3 Windows

In recent times many classrooms have been built without windows Although outward oriented windows may not be essential at least some kind of visual relief is usually recommended This could be a view into an interior enclosed courtyard or into a communal school facility

It is interesting to note that the no-window, environmentally sealed school of the last few years has not necessarily been as energy efficient as schools built twenty or thirty years ago Windows in these older schools permitted solar heating in the winter and openable windows provided natural ventilation, this sometimes being aided by the higher ceilings in the classrooms Natural light also can reduce the amount of illumination needed

4.4.3.4 Siting

Educational buildings should be sited to take advantage of the energy conservation possibilities offered by their location (Ref Sections 2.1 and 4.1). An educational facility can have many components of a different nature as opposed to the rather more homogeneous nature of an office building and these components can be isolated and positioned to take advantage of the possibilities

for energy efficiency on the site. They may also have different use patterns and these should be taken into account. Offices might only be used part of the year, classrooms in certain months, and athletic facilities all year long.

4.4.3.5 Planting

Using plant material to advantage is sometimes overlooked in the design of educational facilities. The advantages of year long shading by evergreens and summer shading by deciduous trees which allow sun penetration in winter should be considered As mentioned in Sections 2.1 and 6.0, planting can favourably modify a site in many other ways.

4.4.3.6 Open Planning

An 'open plan' system for the interior of an educational facility allows heat from the interior zone to transfer to the perimeter and exposed area. This reduces the amount of ductwork needed and generally lessens the burden on the mechanical system.

Spaces with high internal heat gain should be located against the outside walls which have the highest exposure loss.

Completely flexible plans, ones that anticipate change, are sometimes never used and as a result are wasteful in terms of cost of constructional provisions and mechanical and electrical systems Less flexible plans that can be adapted, although with possibly more effort, can prove a less expensive accommodation of change.

4.4.3.7 Demand

As with all building types, the total energy picture should be reviewed and systems chosen which operate efficiently for average rather than peak demand. This demand must be based on more moderate requirements and standards than in the past. For instance, ventilation in cascades, with air flow from classroom to hallway to washroom and then to the outside could be considered. Any system proposed should use passive energy, as several schools in the sunnier parts of the United States already have.

4.4.3.8 Multi-Use

One change in the design of educational facilities that is most advantageous in terms of energy efficiency is the trend toward the construction of such facilities in multi-use developments.

Educational facilities, especially in urban centres, are being built with commercial and residential developments. First of all, this generally brings better and longer, utilization of school facilities.

Secondly, especially with a residential and educational combination, the resultant total building system is able to work on a more even and efficient basis than is possible with individual functions.

The peak energy needs of an educational facility compliment those of a residential segment of a building. A school will have prime daylight peaks and residences higher night time peaks. This combination could probably make better use of thermal storage and other systems which might be used. Such arrangements allow the possibility of a totally self-contained system, or virtually so.

Again, it should be repeated that passive energy conservation should always be a part, if not the starting point, of even the most advanced mechanical and electrical systems for the best possible energy efficiency of an educational building.

4.4.4 Commercial Buildings

Commercial buildings can accommodate a very mixed and changeable variety of uses under one roof. These may range from those needing no natural light or direct exterior exiting, to others for which maximum natural light, orientation to exterior spaces, and direct access to the outside is essential.

In the design considerations for this type of building, the first step is to catalogue exactly the requirements for each type of space to be housed. All too frequently it has been necessary to cover over glazing where none was desired or to close up redundant exterior door openings.

The energy needs for areas should be considered and those of similar nature grouped together. The building can then operate in segments so that, for example, areas which can utilize passive energy conservation techniques most effectively can do so and not be burdened with mechanical systems that would be inappropriate for these areas but are needed elsewhere. Local adjustment for particular requirements are also made more convenient and practical

The reverse of this is true also. Mechanical systems can utilize the thermal differential between areas to assist in internal temperature control. Furthermore, a beneficial balance in peak loading will result if the energy demand in different areas is not concurrent

4.4.4.1 Symbiotic Relations

Areas might work symbiotically with each other, one grouping of spaces protecting another from certain environmental factors or using the inherent qualities of one space to the benefit of another Parking structures, circulation spaces, and storage areas can be useful in this way Grouping of rental stores, restaurants and cinemas, for instance, have interesting potential for energy efficient design also

4.4.4.2 Site Development

Parking lots, if designed correctly with plant material and infrastructure, can be useful for wind protection or generally for adaptation of the micro-climate of the area The reflective and absorbent properties of surface materials greatly influence the micro-climate with consequent effect upon the energy efficiency of a building and comfort of its occupants. Innovative use of water should not be left unconsidered.

4.4.4.3 Roofs

Commercial buildings are especially likely to have large areas of roof surface and in such circumstances special care should be taken in their design. Three areas to note are the insulation, the reflective or absorptive properties of the roof, and the air infiltration characteristics.

Insulation is needed to keep heat in or out, depending on the time of year, and in some ways this can be a constant factor. That is, the same kind and type of insulation will both keep heat in a building and out of it. However, the absorptive, the reflective and air infiltration properties of a roof could be variable for the best utilization of the environment. Depending on the situation, a roof system that is designed to utilize moveable exterior shuttering or manipulatable components might be most advantageous

4.4.4.4 Compact Shape

As with all building types, a compact shape promotes energy efficiency Underground construction can assist in this. (Ref. Section 4.3.2). If areas on grade can be subtly connected to below grade levels, frequently under-utilized spaces can be made available. Further, this type of construction lends itself to a very high insulation level and resultant energy efficiency.

A compact building shape is also made possible by using larger interior floor areas This is facilitated by the connection of smaller spaces, possibly rental, that have little glazing or outside wall area, with adjoining larger spaces that do have these features In this way, the maximum benefit and control can be gained by the exposed portions of the building's surface and glazing. This is where their benefits can be passed on to subservient areas.

It is also possible to construct an energy system that focuses on a larger space and has smaller areas controlled through it. That is, for instance, a large communal area might be designed to be passively cool in the summer and receive solar heating in the winter Although smaller spaces cannot take advantage of this passive design directly, they could indirectly through the larger area

4.4.4.5 Entrances

Commercial buildings often have many entrances and exits. It is very important not to lose any of the advantages gained by an energy efficient building through these areas This is especially difficult if a building or complex is being used by a large number of people and has very high peak use periods.

Air locks, vestibules, revolving doors and a design which anticipates traffic flow and its effects are prerequisites. They will permit an energy efficient transition into the building. Heavy traffic might be used to advantage in areas that require the benefits that its associated air infiltration can bring. This air infiltration can be offset by passive means such as natural solar gain or natural ventilation, locally employed.

4.4.5 Office Buildings

In office buildings energy efficiency can be achieved through passive and active energy conservation.

Considering both of the above methods, the only way to determine for each particular situation which set of choices will be the most beneficial, as is true for all building types, is to evaluate them in terms of life cycle costing. (Ref. Section 7.0). Energy conservation may be achieved with an addition in initial capital investment, with no added

cost, or with a reduction. Only a life cycle costing can determine how initial cost, operating cost, and other economic considerations concerning energy efficiency in the long term can be valued. As with most buildings, there are also concerns other than energy efficiency which must be weighed. It is the balance between energy efficiency, the building's livability and its economic viability that will be most important

4.4.5.1 Compact Shape

A compact building shape (Ref **Section** 4.3 Building Form etc) is the most efficient for energy conservation Heating, ventilation and air conditioning cost, as well as energy, benefit from less building envelope The cost of HVAC services for the 5 metre band of perimeter area in an office building is approximately four times the cost for interior areas

4.4.5.2 Form

Many building forms, including serrations of the building wall, enclosed courtyards, and screened skylights can all make these larger enclosed office spaces more comfortable and desirable, especially those parts most removed from the usual exterior window area. Again, increases in building perimeter must always be weighed against the quality of office space created and the energy balance achieved In most examples to date, energy efficient forms have generated extremely dynamic space to deal with the proportionately larger volumes enclosed In such ways, energy efficiency, when thought of in a positive, creative way, can result in novel and pleasant working environments.

4.4.5.3 Communal Spaces

With an emphasis on communal internal spaces, many unnoticed elements of a building can be exploited Buildings with larger floor areas can utilize internal atrium spaces These lower, proportionately more dense, buildings use less elevatoring and can encourage the use of stairs and thus promote energy efficiency This unnoticed element can be further developed. People will be encouraged to use the stairs if they are not merely dark circulation routes but areas with interesting lighting and planting, possibly overlooking various work areas or other communal spaces When elevators and escalators are used, they can be very dramatically incorporated.

All the above elements, if imaginatively handled, could become the focal points of various internal working spaces and contribute to energy efficiency Initial savings arise from the use of stairs and hence fewer elevators. Secondly, the spaces formed provide pleasant interior views from the office area and reduce the need for wasting external wall area.

Another method to make work areas more pleasant, if they are somewhat distant from the external wall, is to include generous balcony or roof deck spaces immediately adjacent.

4.4.5.4 Glazing

It is typical for glazing in an office building to range upwards from 35% of the total exposed wall area Even a reduction to 30% would produce a great saving while not being particularly noticeable on the interior of the building. This would be especially true if other interior views or features were offered

In discussing windows it should be noted that sometimes it is not so much the amount of window as their proportion, shape and placement that is important. A continuous strip window permitting an unbroken view from a seated position, and not appearing awkward while standing, can be more effective than the more regularly sized positioned windows in giving a sense of the outside This shape of window permits a proportionately smaller area of window glazing to exposed wall surface. Sometimes a small balcony for outside access, or a more fully openable window can magnify the effect of a relatively small segment of glazing.

Blank panels can be used on heavy solar exposures to reduce solar heat gains during summer months and thus reduce the peak demand load on mechanical cooling. Movable sun screens on the inside or outside can both cut solar gains and when appropriate, allow solar gains to augment the building's heating capacity Windows can also be angled both vertically and horizontally to adapt to the position of the sun Building overhangs, trellises and serrations in the walls can protect glazing exposed to potential solar heat gain Positioning of glazing (including skylights) should always use the sun to the building's advantage Windows that can open can be used for ventilation, can work with a building's air conditioning system, or can be used in conjunction with an internal air recycling situation

4.4.5.5 Plant Material

The contribution of plant material to solar protection as well as other energy conserving benefits has been discussed in Section 2.1

4.4.5.6 Lighting/Open Planning

Task lighting and open planning can increase energy efficiency in the building's interior The following comments should be read in conjunction with Section 3.14 which provides a detailed examination of many aspects of artificial illumination, including installation options and their implications for energy consumption

Designed innovatively, neither the position of the work areas nor lighting fixtures are dependent on each other and, ideally, both are flexible The variation in lighting levels this brings about can create extremely pleasant qualities of light when compared with the harshly and evenly overlit spaces commonly found in offices. Indirectly, there will be a saving on the HVAC system also by the reduction in the amount of lighting and heat generated from it. (Ref Section 3.14.2).

It should be possible to turn lights off People will do this when switches are positioned correctly Natural lighting should be utilized when possible (Ref Section 3.14) and, again, office lighting should accommodate this and not be redundant There are automatic devices which can regulate the use of artificial light in naturally lit areas It is preferable, if possible, to construct a situation in which people are able to do this efficiently for themselves

Open planning reduces the complexity of the HVAC system Further, if a building is utilizing larger floor areas and some portions are remote from exterior or interior windows, it allows available light to penetrate as much as possible to these and all working areas.

4.4.5.7 Ventilation

The rate of ventilation can be less in an office building than is usually used presently and still provide a comfortable environment for its occupants (Ref Section 3.9) New standards show greater discrimination in responding to the causes of stale and stuffy environments without the unnecessarily high ventilation rates of the past

4.4.5.8 Thermal Storage

Thermal storage can be one of the main elements in energy conservation in an office building In this concept, surplus energy generated in a building is stored in water-filled thermal storage tanks for future use The need for a supplementary heat source can be completely eliminated in appropriately designed energy conserving office buildings which utilize thermal storage techniques (Ref Sections 3.1, 3.8 and 3.14)

4.4.6 Criteria for Energy Efficient Design of Medical Facilities

The criteria for the building envelope described previously for other building types apply equally to medical facilities

4.4.6.1 Hospital Equipment

Hospital equipment typically accounts for between 20% and 35% of all hospital energy consumption. Recommended procedures for energy conservation include the following

—Appoint equipment manager with technical competence in energy engineering and co-ordinate equipment selection with Building Service Consultants for design integration.
—Review need and detail design of washing machines, fast freezers, ice machines, refrigerated drinking fountains, and other 'convenience' equipment which is usually energy-intensive
—Avoid use of high energy electric booster heaters where low energy steam with storage heaters can be used.
—Investigate possibility of recycling heat from 'grey' drainage water and from equipment exhaust atmospheres.
—Arrange storage and 'rinse-saver' cycling of clean rinse water where applicable, to be integrated with the equipment.
—Include surge tanks to reduce water and steam heating demands

—Operate all equipment at the lowest practicable working pressure
—Generally increase pre-1978 thermal insulation standards for all equipment.
—Consider servo-assisted or manual loading arrangements in place of fully automatic systems where staff supervision is available.

4.4.6.2 Mechanical Ventilation

Mechanical ventilation is advisable for larger hospitals to control the flow of possibly infectious air between functional areas and to maintain stable comfort conditions The ventilation system also provides a convenient method of collecting low grade heat generated within the building and recycling this heat by recirculation or by mechanical extraction for re-use in other parts of the building. Forced ventilation for smoke control is an important life-safety function of the ventilation system in the integrated hospital design

Energy is consumed in pumping the ventilating air to and from the spaces served and in air filtering, heating, cooling, and humidification The pumping energy is proportional to the rate of ventilation and to the pressure exerted to move the air through the system. Thus, a low pressure, low velocity, duct-work system is the preferred method of mechanical ventilation for hospitals. Additional shaft spaces necessary for the large duct work should be allocated early in the concept development

Heat recovery from building effluent, such as exhaust systems and drainage systems should be examined for possible heat transfer to air intakes, domestic hot water storage, and other available heat sinks.

4.4.6.3 Fenestration

The design of windows and their arrangement can provide excellent opportunities for the conservation of energy in a hospital Natural light entering the building can reduce the use of artificial light when properly managed or automatically controlled In winter, solar radiation entering the building through the windows can provide significant heating energy when integrated with mechanical systems designed to compensate for the additional heat source. In summer, direct solar radiation should be minimized by external rather than internal shading to conserve mechanical cooling energy. Window glazing should be studied in detail to evaluate heating, lighting, and cooling effects, leading to the most favourable annual energy consumption The optimum glazing area will differ for each aspect of the building and with the function of the area served.

In the Canadian climate, double glazing is normally necessary for humidity control and triple glazing should be seriously examined for the additional benefits of reduced heat losses and improved comfort levels at lowered temperatures in perimeter spaces The use of tinted glass, reflective glass, and other variations to plain glass should be carefully evaluated since many of these special treatments have evolved from aesthetic and summer glare considerations and may actually increase the annual energy consumption of the hospital

4.4.6.4 Ventilation Zones

Ventilation zones should be matched to the functional zones required by the planning programme. This will minimize the problems of system overlap between adjacent fire-smoke zones and the possible

flow of air-borne infections between functional zones Where the zones exceed 1850 m^2, subdivision may become necessary for life safety purposes and the ventilation zones should be matched to these. The air handling stations needed to serve each zone will thus be no more than 14 200 dm^3/s capacity and this will ensure that low velocity main trunk work is of reasonable size

The relatively small air handling stations resulting from this approach will require less total electrical power than centralized stations and will allow programming of day and night shut down for energy conservation in individual areas

4.4.6.5 Lighting Systems

Twenty-four hour operation of many hospital areas and lighting systems account for a large consumption of electrical energy Efficient design and switching management will produce direct electrical energy savings and an indirect saving of cooling and ventilation energy which would otherwise be necessary to maintain comfort conditions in the area served

The lighting energy required by lighting systems is usually considerably less than 20% of the electrical energy supplied The choice of fixtures and their method of mounting in the room can significantly affect energy consumption and should be carefully evaluated A freely exposed and suspended lighting fixture can be 2 or 3 times more effective than the same fixture recessed into the ceiling Wherever practicable a 'background and task' approach should be taken to lighting systems design

The lighting system should include zone dimming devices with light-sensitive controllers in the occupied space Dimmer zoning should be related to functional zone planning so that complete shut down or reduced lighting levels can be programmed to suit use of the space The control should be arranged to compensate for natural light and for the new, worn, or dirty condition of the lamps

4.4.6.6 Building Envelope Heat and Vapour Transmission

Walls, windows, floors, roofs, and doorways, should be designed to offer high resistance to the transfer of sensible and latent heat, and vapour across the envelope Building codes should be considered as a minimum standard of insulation Use these as base comparisons with high insulation standards and evaluate concurrently with the fenestration glazing energy studies

4.4.6.7 Energy Management

Recommendations for an efficient energy management programme

—Design an Energy Management and Control Centre (EMC) with continuous monitoring of remote equipment.

—Provide for remote switching and adjustment of key equipment and controls.

—Investigate options ranging from manual to fully automated central control of switching programmes and of HVAC trend analysis and adjustments

—Consider combining building life-safety functions and equipment within the EMC Centre under common supervision.

—Include pressure and temperature indications and selective recording and metering of major energy demands, light dimming and electrical load-limiting control at the EMC Centre
—Involve Owner's staff in building commissioning and optimization programmes and in progressive takeover of systems.
—Review staff qualifications and experience and recommend upgrading where appropriate.

4.4.7 Industrial Buildings

Heating and cooling of typical process industry buildings account for 10% to 15% of the total plant energy requirements There is a much greater opportunity for energy savings in the industrial process requirements in comparison to building design Industrial processes, however, release a great amount of energy that can be used in satisfying demands of the building services

4.4.7.1 Systems Integration

During design stages a major effort should be made to integrate energy demands of building services and industrial process services Energy and mass balances have to be calculated for all systems of the plant and building. Appropriate equipment and technology should be considered for each specific situation.

Many industrial plants discharge liquids, solids or gases with high energy content that could be used as a source for another process or environmental control within a plant, such as heating or cooling Stack gases, condensate systems, cooling processes, and incineration of waste products provide potential sources for waste heat recovery

In most food processing plants refrigeration equipment operates twenty four hours a day Integration of energy recovery devices could produce all the hot water required for heating simply by transferring exhausted refrigerant energy to heating water. At the end of the heating season the hot water could be used for food processing or some other demand To maximize the benefits from energy and mass balance analysis, review of the total systems should take place several times during design stages.

4.4.7.2 Industrial Lighting

The purpose of industrial lighting is to provide energy-efficient illumination in quality and quantity sufficient for safety and to enhance visibility and productivity within a pleasant environment

It is essential to investigate and to understand the inter-relationship of the task, the environment and the lighting system. The need for the prudent use of electricity demands conscientious analysis and informed decision making with respect to the design and use of industrial lighting.

In the past, lighting levels in every part of industry have been designed far too high and can be drastically lowered without loss of productivity. Test data for a task of medium difficulty demonstrated that by reducing the required visual performance level of 95% to 89%, the lighting levels could be decreased by a factor of five (from 796 lx to 140 lx).

The following criteria developed by the Illuminating Engineering Research Institute should be analyzed during design stages

—Visibility and 'seeing' Visibility is related to levels of illumination It is almost axiomatic that very high levels of illumination are needed to make dark-coloured, low-contrast tasks as readily visible as light-coloured, high contrast tasks under low levels of illumination. Research demonstrates, however, that in addition to visibility, other factors affecting facility of seeing suggest a minimum of 323 lx on all industrial tasks where there is a sustained seeing requirement

—Pleasing environment Industrial management is increasingly aware that, surrounded by a pleasant environment, people are more content, that it contributes to safety, visibility, better housekeeping, to morale, motivation and productivity Much is being done to create pleasing visual conditions light-coloured interior finishes and machines, good colour combinations, interesting patterns and textures

—Value of Lighting The value of a properly applied industrial lighting system is determined by its cost as related to its benefits The investment in efficient, high-quality lamps and luminaires can contribute to high productivity It can contribute to real savings in human and electrical energy Conversely, a poor lighting system and/or low levels of illumination can increase costs of operation and reduce productivity

4.4.7.3 Underground Facilities

.1 Categories: Current examples of underground space utilization span the full spectrum of industrial activities **Figure 4.4.2.3-1**. For the purpose of analysis the facilities could be grouped into two categories of general space temperature conditions

—Cold—approximately − 20°C Analysis of energy requirements for cold storage facilities shows that an underground location reduces the energy consumption by as much as 90% compared to equivalent above ground facilities

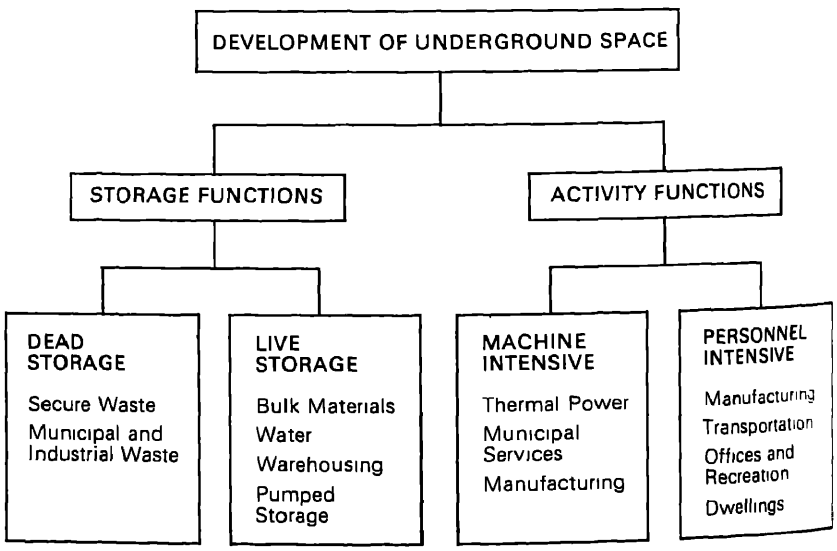

Figure 4.4.7 3-1
Underground space utilization.[1]

—In the event of power disruption, the temperature lost in cold storage facilities below ground is 24 times slower than in those above ground. This has obvious implications for security of inventory against spoilage and the need to install emergency standby power facilities.

—Normal—approximately 20°C: About 50% direct energy savings can be achieved by placing normal temperature facilities underground In general, greater energy efficiency occurs in severe and variable climatic conditions since an underground location offers protection against direct climatic factors.

.2 **Summary**: Analysis indicates that there is a potential for energy conservation in going underground, particularly for a building housing industries requiring large cold storage facilities such as food processing or chemical manufacturing.

Each proposed project should be separately analyzed in light of specific requirements. For example, if a particular plant requires large volumes of fresh air for ventilation purposes, the reduction in energy needed for heating and cooling underground could be offset by the additional energy required for ventilation

A complete cost analysis must include life cycle energy requirements as well as construction, maintenance and transportation costs. Extensive underground facilities requiring excavation are only economically feasible in some locations; for example, if the space is already created by mining or some other activity.

4.4.7.4 Building Envelope

In addition to the criteria for energy efficient design described in Sections 4.0-4.4, special attention should be drawn to the control of building infiltration In some cases this accounts for up to 60% of total heat loss Infiltration expresses the sum of cold air introduced into a building through doors, loading docks, windows, exhaust systems, make-up air and walls. Loading doors, particularly, require protection to prevent substantial energy losses each time they are opened. Depending on circumstances, these losses can be minimized by installation of air locks, canvas or plastic curtains, dock shelters, wind shields,etc

Infiltration control requires computer simulation models to show the inter-related nature of the systems and building envelope For example, the losses through the south wall will affect infiltration on other sides of the building.

However, infiltration can be controlled and energy demand necessary to meet heat losses reduced. In many ways infiltration control is the last frontier in energy conservation because of its complexity.

4.5 Interior Spaces

4.5.1 Design Considerations

Design of interior spaces is integral to the success of energy efficient building design The interior designer as well as engineering consultants should be involved in the design team from the beginning of a project Interior spaces should exploit the new forms a building may take to best utilize both active and passive methods of energy conservation. In this way, the basic energy efficient principles expressed in the architecture can be further strengthened and the interior design will not be merely a repetition of concepts used in more conventional and less energy efficient buildings Choices of finishes and furniture made in the past did not necessarily contribute to the energy well-being of a building In the future, this should not happen.

Interior design will be very much responsible for the public image of energy conservation. It should demonstrate that energy efficient techniques can make daily life more pleasurable and enjoyable

4.5.1.1 Room Layout and grouping

There are many ways for the designer of interiors to achieve passive energy efficiency. In general, in the design of room layouts, areas of similar energy demands (lighting, HVAC, etc) should be grouped together as should odour producing areas (smoking, toilets, kitchens) in order to permit the best servicing appropriate to their needs In terms of plumbing, this grouping is also efficient Areas needing the most illumination, and areas producing extreme environmental conditions such as those in a machinery room should be placed where their individual needs can best be met without being a burden on the remainder of the system

Spaces with the greatest number of occupants and highest traffic volume belong at entry level to reduce elevator needs. Also, rooms accommodating dependent functions should be at the same level or as close as possible to minimize elevator use Those that are used only occasionally should be capable of being closed off and their systems treated separately

Corridors, equipment rooms, toilets and other circulation spaces which do not require the level of environmental control and comfort of other areas should be located as buffer zones They can protect interior spaces against cold or northern exposures and against heat infiltration on the other exposures The areas that generate excess internal heat are best located on colder interior walls so that it can be dissipated and the load on the mechanical system minimized

The above considerations and groupings can reduce the extent and complexity of the mechanical systems and permit heating, cooling ventilation and lighting to be concentrated where they are most utilized. Reference was made previously to cascade ventilation This reduces the amount of air needed for ventilation and simplifies the circulation system when purification is required.

A purification recirculation system avoids having to bring in air from the outside and its necessary heating or cooling before circulation Provision of smoking and non-smoking areas can provide a further opportunity to adjust the technology and contribute to energy conservation

4.5.1.2 Floor Area and Volume

The less the area and volume built, the less, generally speaking, the demand for energy and hence the greater energy efficiency per person or function of that space. Even if waste space is affordable on a first cost basis, it is never affordable over the life cycle of a building when energy conservation and maintenance are taken into account

If a smaller square footage per person is being allocated, open planning and generous communal spaces can offset somewhat limited personal allocations of space

As already mentioned, open planning increases the efficiency of HVAC systems It also permits more effective use of lighting fixtures as the reduced area of partitioning decreases light absorption and hence fewer lights are needed. Open planning, too, makes glazing more visible to areas that conventional room enclosures would have screened off

Communal spaces to be used in the course of a work day, during work breaks and lunch hours, or for circulation, can make the working environment more pleasant if they are handled in a sensitive manner Giving each office and individual work area a little more space could achieve barely noticeable benefits However, a communal space comprising less than the accumulation of these individual spaces could bring about a much greater effect, something very special adding greatly to the working environment.

Open planning could also utilize forms such as courtyards, clerestory lighting or skylighting, again not necessarily appropriate for individual spaces but which could be energy efficient

4.5.1.3 Room Finishes

Light colours can assist in both artificial and natural lighting and, psychologically, they emphasize the openness of areas This characteristic is of particular value where smaller sized spaces are being allocated for particular functions Many studies are available on the luminous reflectance properties of neutral and coloured surfaces and reference should be made to the illuminating Engineering Society Lighting Handbook

It is possible that the room finishes on walls, ceilings, floors, could have further importance in terms of the building's heating and insulative properties. They could have insulative qualities and prevent air infiltration or block out solar gain while perhaps still permitting light to enter and could be heat absorbent or reflective It would be economical if finishes could be incorporated in this way and fulfil both seen and unseen functions.

Reflective surfaces will distribute the natural and artificial lighting that is available. In addition to mirrors and paints a great variety of materials, plastic and wood finishes with reflective properties is available

4.5.1.4 Walls and Windows

If there is a limited amount of window area, its effect can be increased by being set in a larger or appropriately finished window box or configuration. Window openings can be emphasized by mouldings, shuttering systems, or curtains. Sometimes it is the continuity of the glazing rather than the vertical height that gives

4.5 Interior Spaces

the sense of openness and view The important aspect of both natural and artificial light is its quality, not quantity

The design of rounded cornice junctions between walls and ceilings can facilitate interior air flows. This is useful to direct heat back toward living spaces and to prevent heated air from being trapped in such zones

Feature walls, dramatically lighted, offer interesting possibilities to rooms or areas with either little natural light or interior views Again art work may be used for this purpose, such as bold graphic designs or wall coverings with attractive textural quality The free standing placement of sculpture or other three dimensional object might become the focal point of some areas

As far as possible, furniture should be arranged so that it does not obscure the view or block natural light sources, nor should it obstruct air supply or return registers.

4.6 Horizontal and Vertical Constructional Systems:

Horizontal and vertical constructional systems perform a number of functions and meet thermal needs, principally, as follows:

—they support static and resist dynamic loads as well as support their own weight.

—they act as a screen or barrier to eliminate or filter environmental influences, i.e. rain, snow, sunshine, wind and noise.

—the thermal function of the screen is to filter the flow of energy to provide comfortable conditions within the building

The thermal behaviour of a building is pre-determined early in the design process. The initial design decisions will establish patterns of form and construction detail which will effect the life cycle thermal performance. The purpose of the enclosure system is to filter the effects of the outside climate in order to provide comfortable conditions for all activities and uses The best design practice considers the buildings as an enclosure system from the outset concurrently with the development of a thermal concept for the design The function and composition of each special element can then be considered in terms of how it contributes to the total environment of the building

This approach encourages the designer to think in terms of principle and concept from the outset and relies upon the building meeting annual energy budget standards.

Energy budget performance standards provide the opportunity and scope for better and unique architecture The extensive thermal calculations that may be required can be simulated through the use of computer programs The use of non-depletable energy sources for heating and cooling, such as solar, should be encouraged by architects and their potential explored on an individual project basis

Current design practice in the 'light construction industry' utilizes construction details which have evolved on a trial and error basis in response to current techniques and economic imperatives. Nominal minimal thermal standards for these generic building types are determined in prescriptive codes such as ASHRAE Standard 90-75[1] and the NRC *Measures for Energy Conservation in New Buildings* 1978[2] Each construction element (i.e. roofs, walls, floors, soffits, etc.) is dealt with as a separate entity

The NRC *Measures* divides buildings into low energy and high energy types

The low energy type, for example, houses, low rise apartment buildings, nursing homes, motels and heated warehouses require a high thermal resistance for the enclosure elements. The high energy type, exemplified by large offices, recreational, manufacturing, reatil, educational buildings, hospitals and hotels have a lower thermal resistance requirement. In this latter category of buildings, heat is generated by processes, equipment and lighting and it could be counterproductive to over-insulate because of potential cooling loads However, if internal heat gain is successfully controlled, the thermal resistance of the enclosure should be increased accordingly

The prescriptive code represents a value judgement made upon the basis of use, location, state of HVAC technology, the imperatives of conservation and cost benefit analysis.

4.6 Horizontal and Vertical Constructional Systems

4.6.1 Design Principles

It has been established through experience that building density (i e ratio of building volume to site area—specifically, floor space ratio) affects the opportunities in design The condition created by suburban densities (i e floor space ratios in the range 1 1 to 2 1) allows greater emphasis to be placed upon 'direct gain' solar design natural light and ventilation In high urban densities (i e floor space ratios of 2 1 and above) unpredicatable shadowing from other buildings will minimize the solar effect The 'more energy efficient' large-volume to-surface-area building forms have a greater ratio of interior zone spaces, but tend to limit solar, natural light and ventilation possibilities to the exterior zone of the building In this case HVAC systems will play a higher support role These disadvantages can be reduced considerably in courtyard-type buildings They have been discussed in the section on building form, **Section 4.3.1** in the Handbook

4.6.1.1 Integration of HVAC systems

The designer in conjunction with his consultants must establish a thermal concept for the building enclosure in the initial design phase The method of achieving thermal comfort should be established as well as the effectiveness of the building fabric as a filter and the amount of support to be supplied by HVAC systems The building design should, as far as possible, create comfortable conditions by architectural means, integrated HVAC support systems being used on a supplemental basis according to the severity of conditions

Various design measures can be used to cool a building before refrigeration is necessary and the most appropriate construction details should be developed by using established thermal principals

4.6.1.2 Interior functions in Relation to Exposure

Special zones should be established by defining use and proximity to the external envelope The frequency of use, the range of comfort necessary and the loads imposed by the exterior facade and adjacent spaces should be assessed Unheated (by mechanical means) transition spaces used as an adjunct to, or integrated with the function of the building can be designed to have a positive effect upon the thermal performance of the building Entrance foyers, lobbies, corridors, solariums and summer rooms are types of space in common use which represent examples of the traditional wisdom in energy conscious design.

If the building is in a heating mode, it will lose heat to these spaces which have their own ambient temperature If the building is receiving insolation, the balance may be tipped the other way, so that the excess heat in the transitional zone can be transferred to the interior of the building These kinds of spaces will have wider ranges of comfort conditions than the main spaces of the building Adjunct spaces to living, learning and working activities could be a development of this idea Some teaching/learning situations would benefit from a variety of seasonal spaces. The overall building can be thought of as a climate modifier with the space zones and building elements interacting in order to sustain an acceptable range of comfort.

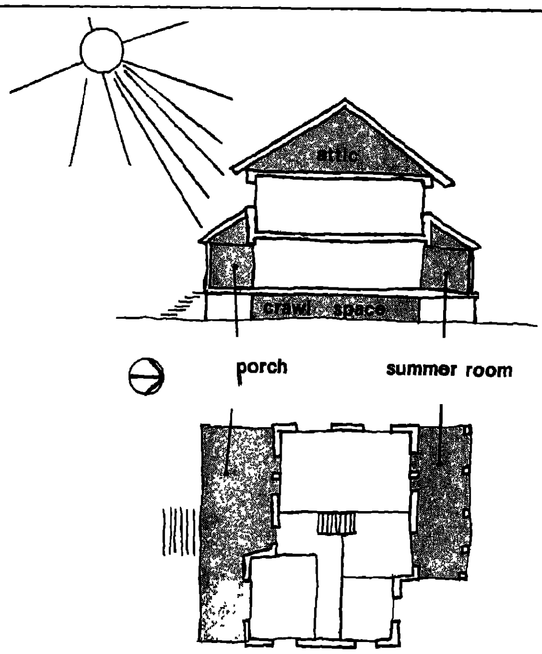

Figure 4.6.1 2
Transition zones of uninsulated frame house

4.6.1.3 Properties of Materials

The fly wheel effect of absorption and re-radiation of materials can reduce the amplitude of mechanical heating cycles The principle of thermal mass storage is used in most passive solar designs. (Ref. Section 3.10.1).

A continuous envelope of insulation placed on the outside of a wall will enable the interior wall mass to retain the heat and re-radiate it to the interior. (Ref Section 3.6.3)

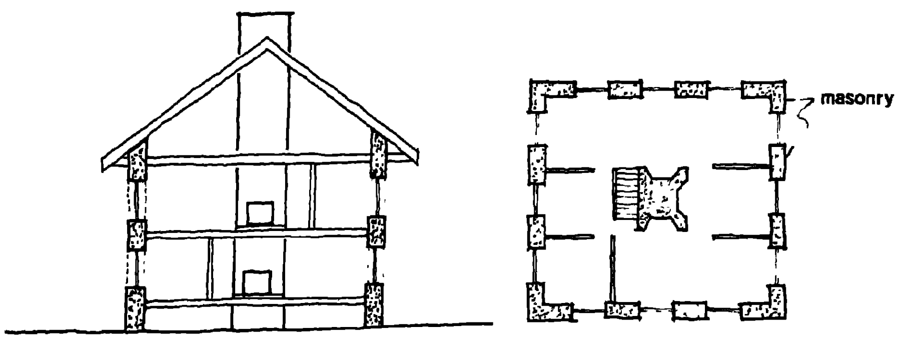

Figure 4.6.1.3
Heat well effect of walls and chimney

4.6.2 Elements of the Enclosure System

The following sections deal with various elements of the enclosure system individually. Each element is treated under two headings First, current practice, where the minimum standard of insulation prescribed by the *Measures of Energy Conservation* is laid out, with typical details and comments on common problems. Second, energy conserving considerations are laid out to encourage consideration of concepts which will improve upon the energy budget implied by the *Measures*. Should such energy conservating designs involve variations from the standards, Section 2 of the *Measures* provides for energy budget comparison to show the improved performance of the proposed construction

The insulation called for in the *Measures* is based upon a cost benefit analysis For this reason, the more expensive insulation assumed for noncombustible construction has a lower *RSI* value than the batt insulation assumed for combustible construction It follows that if energy is to be conserved, the *RSI* values must be considered a minimum. A design with higher *RSI* values would conserve energy and be justified on a cost benefit basis if it can be detailed using inexpensive insulation or if fuel costs are greater than the Canadian average assumed

4.6.2.1 Foundations

.1 Current Practice and Energy Implications·

—Slab on ground

The *Measures for Energy Conservation* call for the *RSI* values shown on the charts below—*The Commentary on Measures for Energy Conservation* states 'Values for both heated and unheated slabs were arbitrarily selected until a method of heat loss calculation for slabs on ground is developed to evaluate optimum insulation on a life cycle cost basis' Maximum thickness of rigid insulation called for is 64 mm. Exterior waterproof insulation is generally used to avoid the common problem of creating a thermal bridge through discontinuity of the insulation [3]

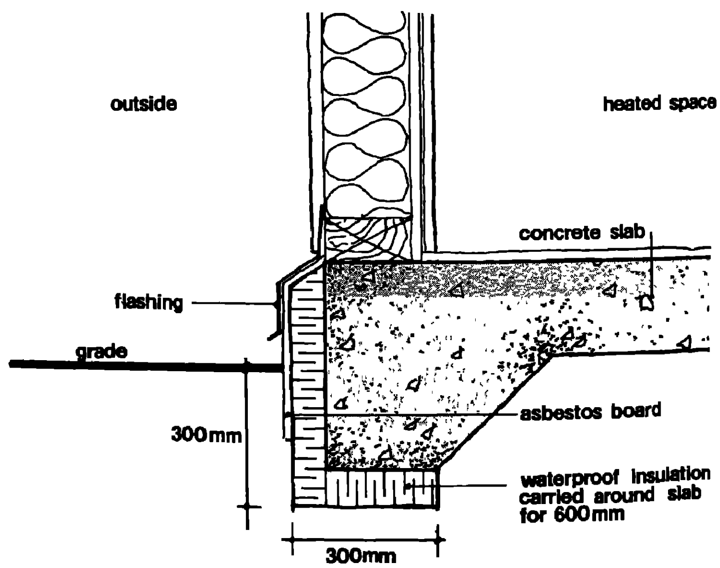

Figure 4.6.2.1-1
Foundations and below grade construction.

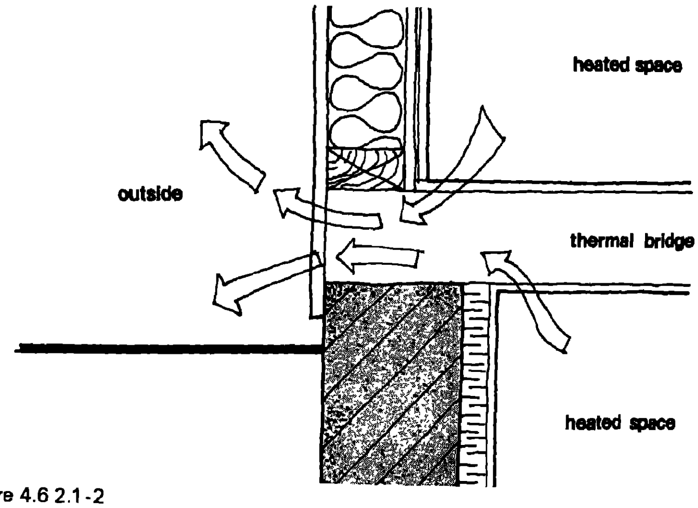

Figure 4.6 2.1-2
Foundations and below grade construction

MINIMUM THERMAL RESISTANCE		
Building Assembly	Maximum Number of Celsius Degree Days	*RSI* $m^2 \cdot °C/W$
Low energy use buildings		
heated slabs	up to 3500	1.3
	5000	1.7
	6500	2.1
	8000 or more	2.5
unheated slabs	up to 3500	0.8
	5000	1.3
	6500	1.7
	8000 or more	2.1
High energy use buildings		
heated slabs	up to 3500	0.8
	5000	1.3
	6500	1.7
	8000 or more	2.1
unheated slabs	up to 3500	0.8
	5000	0.8
	6500	1.3
	8000 or more	1.7

Table 4.6 2.1-T_1
Minimum thermal resistance for heated and unheated slabs[4]

MINIMUM THERMAL RESISTANCE		
Foundation Wall Assembly	Maximum Number of Celsius Degree Days	*RSI* $m^2 \cdot °C/W$
Low energy use buildings	up to 3500	1.6
	5000	1.6
	6500	1.6
	8000 or more	1.6
High energy use buildings	up to 3500	1.6
	5000	1.6
	6500	1.6
	8000 or more	1.6

Table 4.6.2.1-T_2.
Minimum thermal resistance for foundation wall assemblies separating heated space from unheated space, outside air or adjacent earth.[5]

—Crawl Spaces
The need for ventilation in crawl spaces normally makes it necessary to leave them unheated and insulate the floor construction Required *RSI* values for floor construction thermal resistance are shown in the *Measures for Energy Conservation.*[6]

In the case that a crawl space is heated, it will require insulation at least equal to that called for in basements. Note that the N B C Section 9-26 56 specifies that the insulation be stopped 50 mm above the floor if water can be anticipated

—Basements:
Concrete basements are not insulated unless they contain occupied spaces. If unheated, the floor assembly above requires insulation as for an unheated crawl space.

If heated, insulation as shown in the figure below is required from the underside of the floor to 600 mm below grade

A common fault is the creation of a thermal bridge caused by the discontinuity of insulation at the basement ceiling

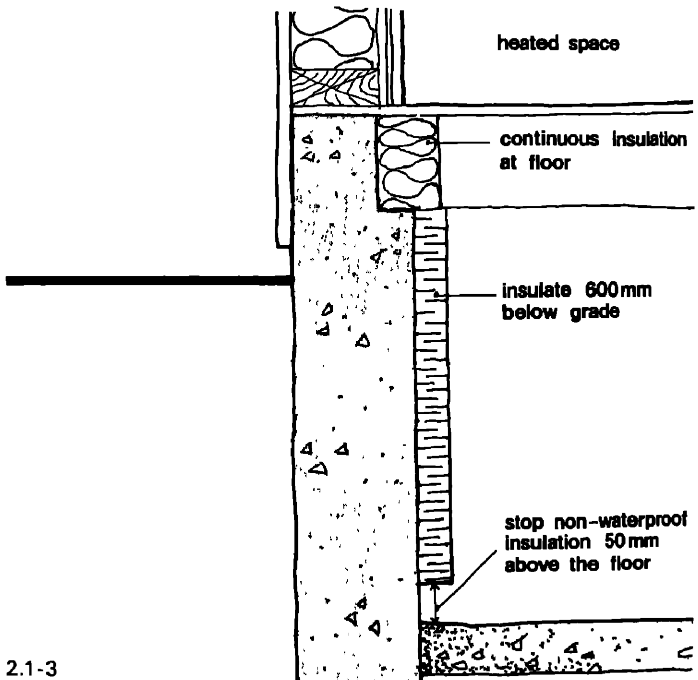

Figure 4.6 2.1-3
Heated crawl space

.2 Energy Conserving Considerations:
—Insulation and heat flow from earth.
It may be an advantage for certain uses to benefit from the ambient temperatures of the ground The root cellar effect is not new or an unknown idea The below ground space will gain heat from, or lose it to, the earth (if uninsulated) and the temperature will even-out to ground temperature

The heat sink effect of earth can best be exploited in climates with extreme temperatures. In hot, arid desert climates the lower temperatures of the earth can be used either by building partially below ground or circulating the cold air from a below grade space. In some arctic conditions there is a benefit if the ground temperature is higher than the combined cooling effects of air

temperature and wind In temperate regions, the average annual temperature of the ground may be lower than the average ambient air temperature so that the effect will be to lower the air temperature rather than save heat

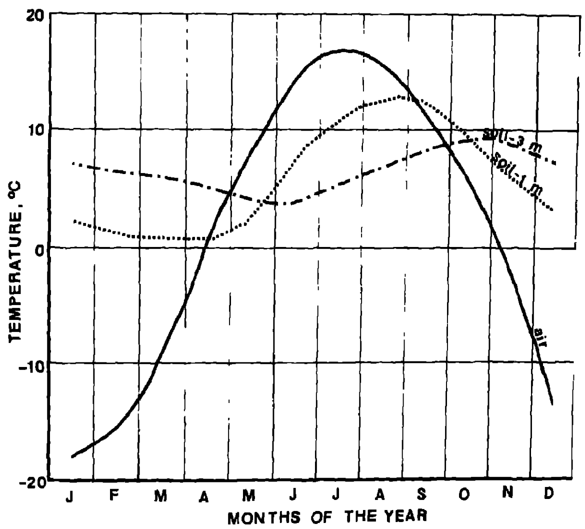

Figure 4.6.2.1-4
Normandin P Q Air temperature and soil temperatures at 1 m and 3 m below surface

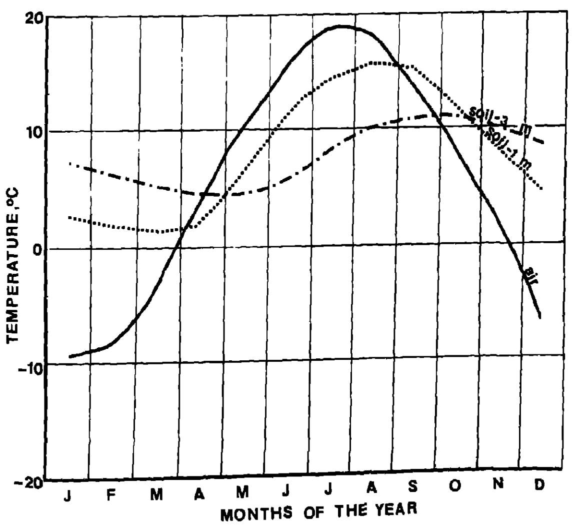

Figure 4.6.2 1-5
Fredricton Air temperature and soil temperatures at 1 m and 3 m below surface

—Building below grade or with berms:
The principal benefit other than heat flow advantages, as previously described, and reduction of heat loss from wind chill, is derived from the fact that the enclosure system (floors, walls, roofs) can be designed to respond to a narrow temperature range If the soil depth is sufficient, the external conditions will not vary

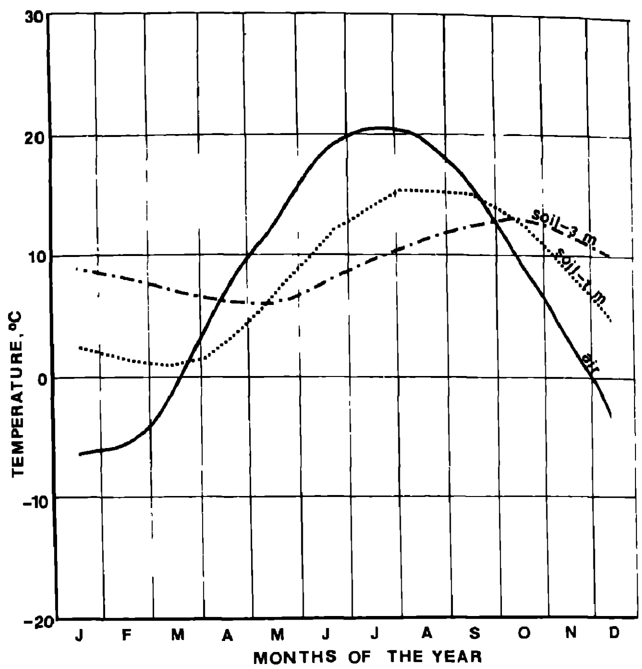

Figure 4 6.2 1-6
Toronto Air temperature and soil temperatures at 1 m and 3 m below surface

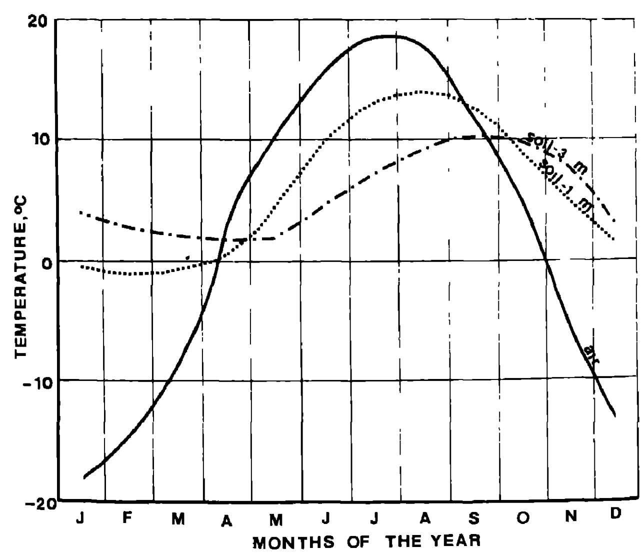

Figure 4.6.2.1-7
Saskatoon Air temperature and soil temperatures at 1 m and 3 m below surface

significantly year round. Berm construction can also be used to control and divert the wind in order to create a more acceptable micro climate adjacent to the building An early awareness of the potential benefits of in-ground construction lead to the development of the subterranean or earth covered dwellings described in **Section 2.1.7** of the Handbook.

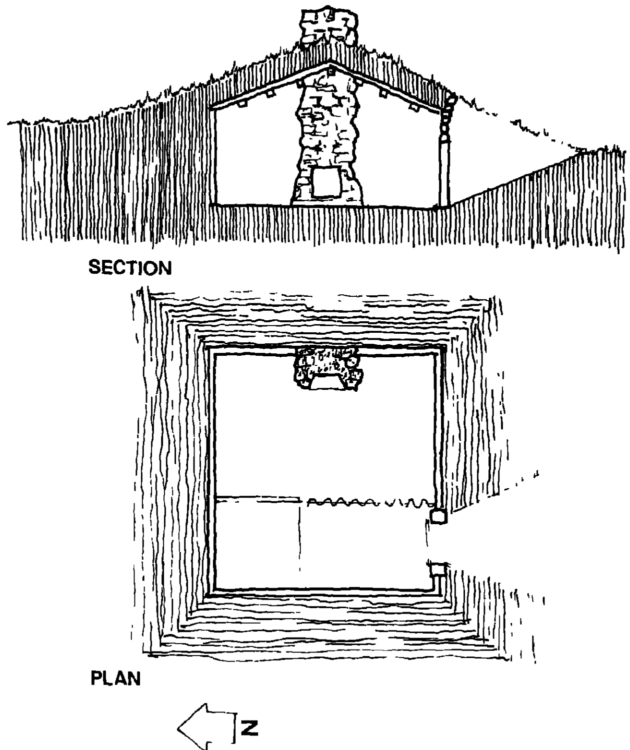

Figure 4 6 2 1-8
Prairie sod shack

4.6.2.2
Floor Construction and Floor Finishes

.1 Current Practice and Energy Implications: The thermal resistance required for floors and soffits separating heated spaces from unheated can be determined from the following table

MINIMUM THERMAL RESISTANCE		
Floor Assembly	Maximum Number of Celsius Degree Days	RSI m² °C/W
High energy use buildings combustible construction permitted	up to 3500	3 6
	5000	4 7
	6500	4 7
	8000 and over	4 7
noncombustible construction required	up to 3500	1 9
	5000	2 5
	6500	3 0
	8000 and over	3 4
Low energy use buildings combustible construction permitted	up to 3500	4 7
	5000	4 7
	6500	4 7
	8000 and over	4 7
noncombustible construction required	up to 3500	2 5
	5000	3 0
	6500	3 4
	8000 and over	3 7

Table 4.6 2.2-T_1
Thermal resistance required for floors, with floor assemblies separating heated space from unheated space or the exterior [7]

.2 Energy Conserving Considerations: Transition zone design
The NRC *Measures for Energy Conservation in New Buildings*[6] recognizes the effect of transition zones in Section 3 3 3 but only considers them equivalent to one layer of glazing The use of such zones to amplify solar energy also requires the storage and re-radiation of that energy In a multiple storey structure the edge of the floor system can be used as a storage element The mass of a reinforced concrete floor system can be easily increased Thermal mass can be added to steel frame structures with an in-situ strip slab over the steel decking or by using precast light-weight concrete panels

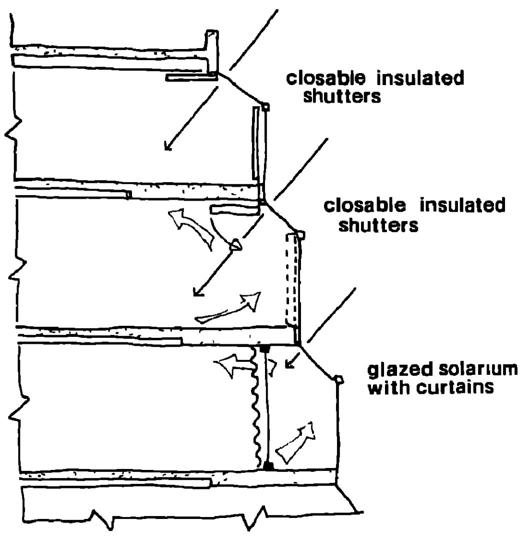

Figure 4 6.2 2-1
Multi-storey edge zone design with radiant slab

Shutters are required to enclose the space at night so that the re-radiation will have some benefit Colour and surface finish of floors are important factors in an effective absorption, re-radiation cycle Adjacent surfaces, e.g walls and ceilings, will also receive re-radiated energy and become storage elements

The use of some direct gain solar features will create 'hot spots' in the building which must be compensated for by more open planning. Spaces 1½-2 storeys high will enhance air convection currents so that return ducts should be placed at the top of the space The design approach should take into consideration changes in attitude and behaviour which direct gain features imply A greater adaptability towards space use requires that the floor construction and mechanical systems are optimized to meet a range of needs

A common fault in floor construction is edge heat loss due to discontinuity of insulation where the floor meets the wall construction.

Floor finish is usually not included in calculating the insulation value of the floor assembly as it is a minor contributor to the total insulation and may be changed by the user of the building. Nevertheless, it is a major factor in the psychological sense of comfort Carpet, wood or cork floors 'seem' warmer than tile or concrete. This is an important factor based on our direct experience of bare feet on

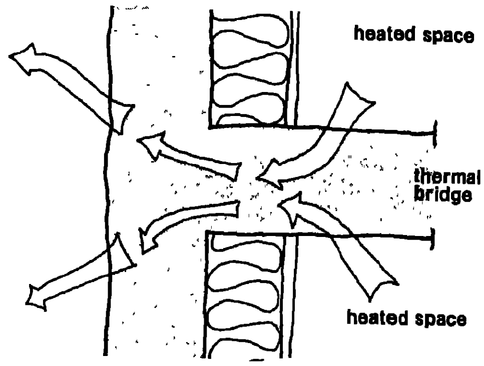

Figure 4.6 2.2-2
Thermal bridge at floor

'cool' surfaces with high conductance such as tile and 'warm' surfaces with low conductance such as carpet

Floors require insulation whenever they separate spaces having differing temperatures. This includes soffits, as well as floors separating crawl spaces, parking etc. from occupied spaces.

Soffit insulation must be at least equal to wall insulation and preferably have a higher *U* value Because of the discomfort caused by cold floors, supplementary heating or other provision to deliver heat to floors over soffits is recommended. The suspended construction of soffits tends to create cold bridging which must be broken with appropriate thermal separators having a thermal resistance of at least 25% of the assembly they bridge.

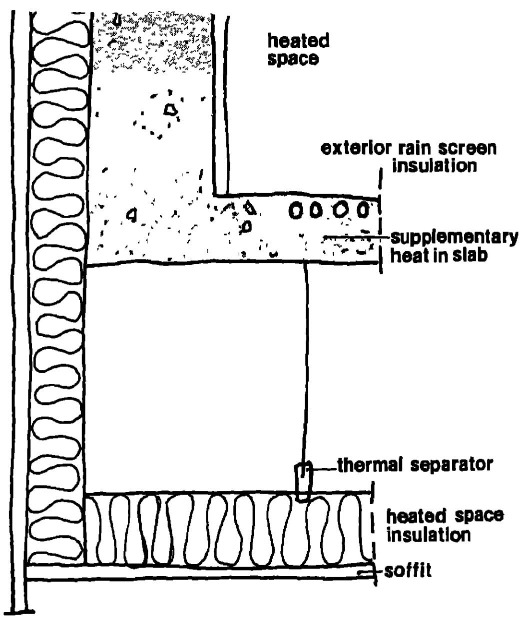

Figure 4.6.2.2-3
Typical soffit detail.

4.6.2.3 Ceiling and Roof Construction

.1 Current Practice and Energy Implications: The *Measures for Energy Conservation* recommended thermal resistance for roof insulation are as laid out in the following table:

MINIMUM THERMAL RESISTANCE		
Building Assembly	Maximum Number of Celsius Degree Days	RSI m² °C/W
High energy use buildings combustible construction permitted	up to 3500	3 6
	5000	4 7
	6500	5 6
	8000 and over	6 4
noncombustible construction required	up to 3500	1 9
	5000	2 5
	6500	3 0
	8000 and over	3 4
Low energy use buildings combustible construction permitted	up to 3500	4 7
	5000	5 6
	6500	6 4
	8000 and over	7 1
noncombustible construction required	up to 3500	2 5
	5000	3 0
	6500	3 4
	8000 and over	3 7

Table 4.6 2 3-T_1
Recommended thermal resistance for roof insulation, with roof or ceiling assemblies separating heated space from unheated space or the exterior [9]

—Flat Roofs

The inverted roof membrane assembly provides insulation at the exterior limit of the enclosure system This provides satisfactory insulation for concrete and steel construction and for roofs where travelled surfaces are required It is also a useful technique for improving roof insulation on retrofit projects

Batt insulation with adequate ventilation is satisfactory with joist construction although the need for thicker insulation tends to obstruct the free flow of ventilation air required to avoid condensation and deterioration of wood structural members

—Attics

The provision of an unheated attic in wood frame construction has the advantage of providing a buffer space between inside and out and allowing the use of inexpensive granular fill and fiberglas batt insulation.

In concrete and steel construction, unheated attic or roof spaces are difficult to detail without creating thermal bridges It is generally best to follow the principle of keeping the insulation outside the structure, placing it is near the outer perimeter as possible

.2 **Energy Conserving Considerations:**

—Attic space as heat sink.

Conventional residential wood frame construction uses the pitched roof as a rain screen, with the insulation over the ceiling of liveable areas A minor heat sink effect is created as the attic space heats up during the day and re-radiates the energy at night This effect can be enhanced by enclosing the attic for air storage and providing manually operated louvres to control the heat build-up. The warm air can then be drawn into the rest of the house by fan.

—Roof as 'Trombe' Storage
The principal of the 'Trombe wall' can, in theory, be adapted to roof elements (Masonry wall absorbs energy from the sun and re-radiates it at night. The effect is amplified by double glazing on the outside so that the space between acts as a hot air convector). The idea can be adapted for southern facing roof surfaces, but requires masonry construction. Horizontal roof slabs have this effect in moderate climates.

Note The 'Trombe' idea depends upon the radiant effect of a critical mass of masonry and its relation to reasonably predictable weather cycles (i e it works well in Alpine-Mediterranean and Colorado climates) The difficulty arises in providing insulation of the roof slab for cold spells and Canadian winter conditions. A positive trade-off may be struck in some regions by using the storage capacity of the denser insulation materials.

—Ceiling tile as storage element.
M I T. has developed a direct gain system which focuses solar radiation onto the ceiling of the occupied space by using special reflecting venetian blinds The ceiling tile has a high energy storage capacity through the use of Glauber's salts Energy is re-radiated in cloudy periods and at night Such a system is limited to the exterior zone

4.6.2.4 Stairways, Elevator Shafts etc.

.1 Current Practice and Energy Implications: The chimney effect of all vertical shafts makes this a major source of exfiltration heat losses A 1972 NRC study showed that a simple residential chimney left open accounted for more than 10% of the total heat loss.

In cases where shafts require exposure to outside air for fire protection or other reasons insulation is required between the shaft and heated spaces

The *Measures for Energy Conservation* give, as an example, an interior elevator shaft terminating within an unheated garage located below heated space The designer may treat either as heated space or as unheated space

If the shaft is considered as heated space, the walls and floor enclosing that part of the shaft located below the heated portion of the building would have to be insulated and, in addition, because the elevator doors would not limit infiltration into the shaft, a vestibule would be required at each garage level served by the elevator.

If, on the other hand, the shaft is considered to be unheated space, the walls separating it from heated space would have to be insulated and, in addition, because the elevator doors would not limit infiltration from the shaft into the heated building, buffering vestibules would be required at each heated floor served.

4.6.2.5 Roof Openings and Skylights

.1 Current Practice and Energy Implications: Solar gain from skylights can provide supplementary heat but unless care is taken, will require additional energy for cooling to remove excess heat.

The build-up of excess heat is commonly avoided by the use of the same devices used in windows, such as heat absorbing glass solar screens and exterior and interior blinds.

The provision of openings for natural ventilation, wherever possible will also be of assistance

Heat loss from roof openings and skylights is also particularly severe due to the higher temperatures at ceiling level and the greater pressure differential and wind velocities associated with roofs Double, or triple glazing, glazing the bottom of the skylight opening to eliminate the inverted well effect, and/or the provision of insulated shutters will all create more than normal energy savings in this area

The *Measures for Energy Conservation* call for double glazing with 6 mm or more air spaces (thermal resistance of 0 30 m² °C/W) for areas with 6500 degree days and triple glazing (thermal resistance of 0.45 m² °C/W) for colder areas [10]

Skylights are also indicated in the maximum area of glass limits, (15% of floor and 40% of wall for low energy buildings) At the same time the additional area allowed for south facing glazing is worth considering in skylight design Article 3 3 6 of the *Measures* provides for double the normal glass area if provision is made for distribution of the solar gain

.2 **Energy Conserving Considerations:**

—Skylight energy control systems
There are a number of proprietary control systems on the market manual and semi-automatic, that are designed to function both as sun louvres and night insulation ('sky-lid', etc) The availability and effectiveness for specific conditions of these products should be investigated before resorting to a custom design, fabrication and insulation

—Interior thermal mass storage

—Skylights can be used as the means for amplifying solar radiation If they face south and are placed towards the rear (north) of the building an interior passive storage element can be introduced

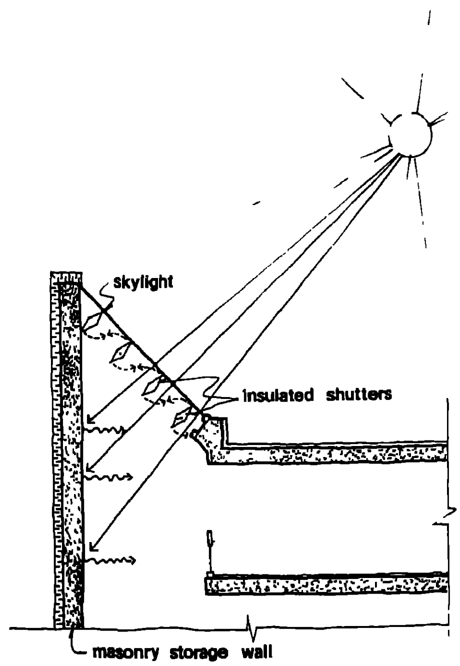

Figure 4.6.2.5-1
Interior thermal mass storage.

Insulated shutters are required to seal the space at night. This application of the Trombe principle obviates the need to occupy the premium south facade with opaque wall areas. It also partially overcomes the problem of the slow morning heat up phase of the conventional 'Trombe wall' design

Substituting water filled plastic or steel tubes as the storage media adds two additional features. The thermal currents within the tube will ensure an even temperature for the storage over its full height, more quickly than the masonry equivalent. The system can be finely tuned by the addition or subtraction of storage capacity after construction is complete i.e. water can be drained off or tubes can be added or removed until the best seasonal balance is obtained.

4.7 Walls and Curtain Walls

4.7.1 Design and Function:

Two principal measures in wall construction affect energy consumption
—thermal insulation
—control of air leakage[1,2]

Thicknesses of insulation suitable for various areas of the country can be derived from NRCC 16574 which is *Proposed Measures for Energy Conservation in New Buildings* 1978 [3] Insulation in the thicknesses proposed in that document must be used with care The enlarged cavity will affect the strength of the wall, air leakage behind the insulation will drastically affect its usefulness and heat bridges, particularly of metal, will reduce the effectiveness of insulation

Control of air leakage is a matter of providing an air-tight skin all around the building This skin must be able to flex without damage at all points of differential movement in the enclosure Lack of care in the selection and installation of an air/vapour barrier may cause serious deterioration in the wall through condensation and freezing

Simply stated, the solution comprises a 'structural' enclosure wrepped in an air-tight, vapour-tight skin The skin is tightly wrapped in insulation These elements are then protected by a rain screen As elegant as this solution is, it is not fool-proof and the components must be assembled with some understanding of their nature and their purpose [4] A discussion of this assembly follows

4.7.1.1 A 'Structural' Enclosure

At some place in the wall a plane exists that stops the wind This plane may be termed the 'skin' Because it stops the wind, the skin must be supported by a wall capable of sustaining the wind loads and of transmitting them to the building frame, where there is one In many areas it must also be capable of sustaining the earthquake loads of the total wall mass and transmitting them to the frame

Rule 1· Fill the building frame with masonry, concrete or metal wall designed to transmit horizontal loads to the frame

4.7.1.2 Creep and Deflection

The structural frame will deflect under load The 'structural' walls under discussion are **not** designed to take gravity loads, so the wall must be held down from the beams to allow the beams to deflect (If the walls could take the load there would be no need for the beam) In concrete frames there is another, less understood deflection, plastic creep [5] It can amount to 2 cm-3 cm in a 10 storey column In beams, creep deflection may exceed elastic deflection by 300% to 400% There is a limit to how much of either kind of deflection can be accommodated

Rule 2 Determine by structural analysis the amount of elastic deflection and creep that can be expected Adjust the walls to allow for this movement

4.7.1.3 The Skin

Once we have an enclosure capable of withstanding wind forces, we must make sure that air cannot penetrate This is the most important and difficult part of the enclosure. Most enclosure difficulties can be traced to air leakage Infiltration brings dirt into the building, freezes pipes and makes humidification difficult Its uncontrolled nature plays havoc with the HVAC system. Exfiltration wastes heat in unbelievable amounts and, more seriously, causes condensation and ice buildup within the walls [6]

The most common way of applying the skin to concrete blocks is to trowel on a continuous coat of mastic. This is hard to do, for applicators must work around such protrusions as masonry anchors or insulation anchors. Attempts at spraying have not been successful, mainly because of poor workmanship in the blockwork This coat should not be used to hold the insulation because it must be inspected. Unless this skin is applied to the outside of the blocks, cold air will easily penetrate the insulation and block masonry and undo the value of the insulation

Where this wall abutts concrete columns, the joint should be caulked, for there will be shrinkage of the blocks well beyond the elastic capacity of the mastic [7] Caulking must have a proper shape and be properly backed up A bead of caulking over the crack will not do. The open joint between blocks and the spandrel beam above must also be caulked or closed with a flexible membrane cemented and mechanically fastened to the beam and wall

Poured-in-place and precast concrete panel walls are quite air-tight and only need the joint treatment mentioned above. Theoretically the same thing can be said for metal walls, noting that there will likely be more joints and that metal has a greater co-efficient of expansion

Metal studs and drywall can be used for the 'structural' wall. The outer gypsum board should be placed just outside the surface of the columns and beams At each column and beam, form an expansion joint from flexible membrane cemented and mechanically fastened to each surface Metal stud walls are strong enough but normally not nearly stiff enough to properly support brick masonry A relative stiffness comparison of brick versus drywall and metal studs should be prepared by the structural engineering consultant.

To the writer's knowledge it is impossible to make airtight joints to a steel frame For that reason, steel frames should be set inside the 'structural' wall with properly made-up movement joints in front of each column and spandrel.

Rule 3 Apply a continuous air-tight, vapour-tight skin to the 'structural' wall with adequate provision for the movements to be encountered in the walls and frame. Join this membrane to the roof membrane

4.7.1.4 Insulation

The next step in the wall assembly is the application of insulation to prevent heat loss Thicknesses are recommended by NRCC #16574 Studies have shown that a 2 mm space behind insulation boards can reduce the insulation value by 40% To eliminate this problem, the insulation should be mechanically fastened into a full coat of mastic Do not use daubs of mastic

In addition, walls that are not perfectly true-to-line should be insulated with material flexible enough to follow the contours of the wall See that metal supports for the cladding do not negate the insulation. For a 100 mm thickness, 160 mm^2 of aluminum conducts as much heat as 1 m^2 of insulation and thus would reduce the value of the insulation to half its original value.

Rule 4: Insulate on the outside of skin, keeping the insulation tight to the skin.

4.7.1.5 The Rainscreen

The assembly should now be protected with a rainscreen [8] The rainscreen principle as applied to walls is described in detail in Section 4.9.1 The following comments relate to constructional details of the rainscreen which warrant careful attention

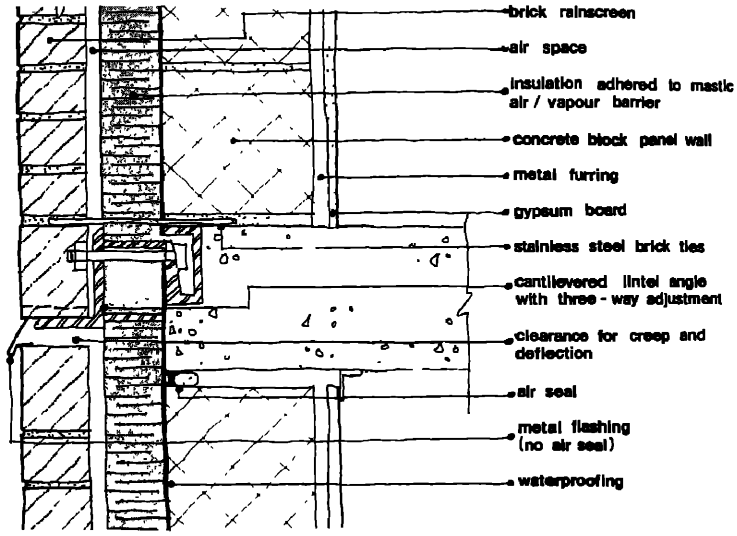

Figure 4 7 1 5-1
Wall-floor junction concrete frame

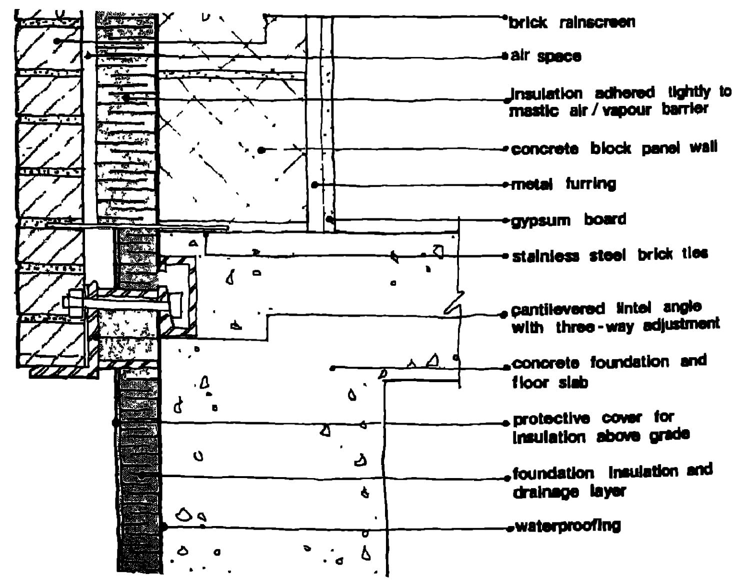

Figure 4.7 1.5-2
Foundation—wall junction

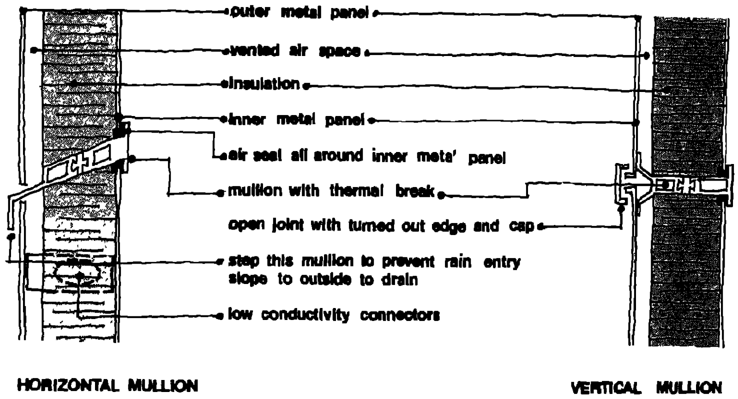

Figure 4 7 1 5-3
Principles applied to curtain wall

A rainscreen is a water-shedding device as opposed to a waterproof skin. It is formed of overlapping panels whether they be metal, precast concrete, brick or wood. With brick, an actual overlap is not possible and this feature must be achieved with flashing. The lap should be adequate to prevent rain access, open to allow some pressure equalization and sloped to provide drainage. Think of shingles when designing it Also, make sure that the cladding or rainscreen can accommodate the frame movement that has been allowed for in the 'structural' wall [9] For instance, joints below brick lintels should not be filled with mortar It is important that the top of the rainscreen be protected by a metal cap and flexible, waterproof membrane sloped to the roof

Rule 5 Protect the other elements of the enclosure with an open rainscreen

4.8 Doors and Windows

4.8.1 Design and Function

The design or specification of doors and windows for increased energy conservation requires that the **energy liabilities** of devices that generally have poor insulating characteristics be minimized, while the **environmental assets** be maximized These assets include the primary function of windows and glazed doors—that of natural light (which reduces the electrical requirement for artificial lighting) —and the potential of positive heat gain during the winter (which reduces the energy requirement for heating). The liabilities of windows and doors relate primarily to heat loss during the winter (which raises the energy requirement for heating) and heat gain during the summer (which raises the air conditioning load)

4.8.1.1 Construction

A window or door system consists of the following
—the frame and sash
—the infill, solid or glazing
—the weatherstripping between frame and sash
—the fittings hinges, sliding tracks, etc.
—the connection of frame to rough opening.

The design decisions taken with regard to each of these constituents will affect the energy performance of the window or door

The materials used for the frame and sash will determine mainly the heat loss through transmission The materials most commonly used in diminishing thermal resistance, are
—PVC covered wood, metal covered wood
—wood
—PVC, metal with insulated core
—aluminum, steel with interrupted cold bridge
—aluminum with weatherstripping
—steel

The materials used for infill, particularly in the case of glazed doors and windows, are usually the main determinant in the insulating

THERMAL RESISTANCE OF FRAME-SASH-INFILL ASSEMBLIES			
	Frame Material		
Infill Material	Wood Wood/PVC	Steel/Aluminum with interrupted cold bridges	Steel/ Aluminum
Insulated glazing (6 mm)	0 30	0 28	–
Insulated glazing (12 mm)	0 33	0 30	0 28
Triple glazing	0 53	0 47	0 43
Double glazing (20 mm -40 mm)	0 39	0 36	0 33
Double glazing (40 mm - 70 mm)	0 43	0 39	0 36
Double glazing (+70 mm)	0 39	—	–

Table 4.8 1.1-T_1
Thermal resistance, *RSI*, of frame-sash-infill assemblies [8]

value of the door. Higher insulation is achieved through the use of multiple layers of glass. Some typical *RSI* values are:
—single glazing *RSI* = 0.15
—insulated double glazing (6 mm) *RSI* = 0 27
—insulated double glazing (12 mm) *RSI* = 0.30
—triple glazing *RSI* = 0.48
—double glazing (+ 70 mm) *RSI* = 0.31

The final thermal resistance of the frame-sash-infill assembly, as regards heat loss through transmission, is determined by the combination of various options, **Table 4.8.1.1-T_1**.

For most windows and doors, heat loss through transmission represents only half of the total heat loss, the remainder is the result of convective losses, which are a function of the air tightness of the sash-frame interface. Air tightness is usually achieved through some form of weatherstripping (gaskets, felts, metal strips) depending on the quality of the window and the method of closure, **Figure 4.8.1.1-1**

The following table gives the amount of air leakage per meter of joint for a number of frame materials and closure systems [1]

AIR LEAKAGE	
Frame Materials and Closure Systems	Air Leakage per Metre of Joint
aluminum casement windows	0 78 L/s
wood casement windows	0 78 L/s
aluminum and wood doors	0 78 L/s
wood sliding doors and windows	1 16 L/s
aluminum sliding doors and windows	1 16 L/s
steel doors and windows	1 55 L/s
un-weatherstripped aluminum windows	1 55 L/s

Table 4.8.1 1-T_2
Air leakage comparisons

Air leakage can be reduced by additional glazing in the form of storm sashes or storm doors, hence double glazing with storm sash is a more energy effective device than triple glazing.[2, 3]

The fittings will have an effect on the air tightness of the assembly, since certain types of closure systems require hardware that penetrates the sash or frame In general the types of closure systems, in diminishing air tightness, are
—fixed windows
—casement windows, hinged doors
—sliding windows and doors
—awning windows
—pivoted windows.

The method adopted to connect the frame to the rough opening can likewise affect air tightness, depending on the method used to seal or close the tolerance gap. This is usually done through the use of casings and mouldings, or with mastics and sealants

The window can be described in a number of ways when taking into account energy conservation It is described geometrically by
—window area, (width × height) = A_w

—glass area, (width × height) = A_g
—frame area, $(A_w - A_g) = A_f$
—crack length, (circumference of sash) = l

Heat loss transmission is based on A_g and A_f Infiltration is based on l Factors are used to allow for the type of closure system used and for the quality of the product

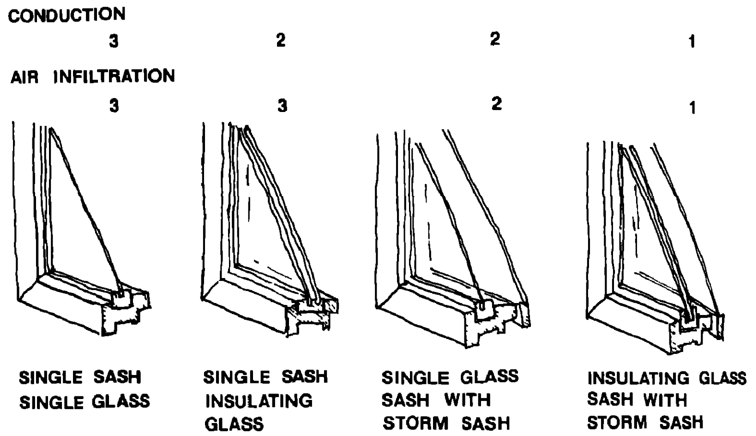

Figure 4 8.1 1-1
Relative amounts of heat loss by conduction and air infiltration for various combinations of window sash and glass [4]

4.8.1.2 Natural Light

The traditional function of windows and glazed doors is to permit illumination Though the use of natural light is not emphasized in most North American buildings, it continues to be an important source of illumination for buildings in a number of countries [5, 6, 7] Since artificial lighting consumes a significant portion of generated electricity (20% in the United States according to FEA, Washington[8]), the use of windows to provide natural light is an important energy conserving design tool

The design of buildings to maximize natural light should take into account window placement, orientation and dimensioning with respect to lighting requirements (task lighting, background, etc) The largest amounts of glazing should be in work areas, rather than in circulation zones The use of tinted or reflective glass reduces the effectiveness of glazing as light source

4.8.1.3 Positive Heat Gain

The amount of solar energy that is received through a south-facing window in most parts of Canada is much greater during the winter than during the summer. Likewise, the amount received through a south window is significantly greater than received through east or west windows during the winter Table 4.8.1.3-T_1 indicates the average daily solar radiation falling on windows oriented south, east, and west, at latitudes 43°-55° north.[9]

The location of openings on south facades (or south east, rather than south west) and the resulting heat gain during the winter, is referred to as 'solar tempering' or 'direct gain' For example, if 104.7 kJ are falling on a window, and if the window is double glazed, about 75% of the energy, (79.5 kJ) will actually penetrate

the building. If the average temperature outside is 0°C, the heat loss during 24 hours will be about 41.9 kJ. Hence the net gain is 37.7 kJ and the efficiency of the window as a 'solar collector' is 36%. It is likely that the heating requirements of buildings could be reduced by 15%-20% through the use of windows and glazed doors, properly oriented to take advantage of positive heat gain [10]

DAILY SOLAR RADIATION			
Month	Solar Radiation, kJ/m², on a Vertical Surface Facing·		
	South	East	West
October	17 640	12 038	1 672
November	16 845	8 402	1 129
December	15 675	6 563	878
January	17 180	8 527	1 129
February	18 392	12 498	1 588
March	16 804	18 434	2 341

Table 4.8 1 3-T_1
Average daily solar radiation, winter

4.8.1.4 Negative Heat Gain

Heat gain during the summer is not only **not** useful, it represents, in air conditioned buildings, an additional energy requirement. Windows facing west are neither a useful source of solar heat during the winter, nor do they gain much heat during the summer (though they may be source of glare), east windows, however, allow more than twice as much heat to enter the building during the summer, and can be a serious energy liability. **Table 4.8.1.4-T_1** compares average daily solar radiation falling on windows oriented south, east and west, at latitudes 43°-55° north [11]

DAILY SOLAR RADIATION			
Month	Solar Radiation, kJ/m², on a Vertical Surface Facing·		
	South	East	West
April	12 749	21 903	3 177
May	9 823	23 366	3 846
June	8 736	24 286	4 138
July	9 656	23 073	4 012
August	12 331	21 109	3 428
September	16 218	17 389	2 466

Table 4 8.1 4-T_1
Average daily solar radiation, summer

Negative heat gain through south facing windows may be easily controlled through the use of overhangs and horizontal shading devices which do not affect either winter heat gain or natural light entry. Negative heat gain through east facing windows can be controlled through the use of vertical shading devices, though these will affect natural light entry. The use of tinted or reflective glass will control negative heat gain, but it will also diminish positive heat gain as well as natural light, reference **Section 3.6.5** Glazing.

4.8.1.5 Heat Loss

Unprotected windows and glazed doors, irrespective of orientation, result in significant heat loss to the building during the winter. It has been estimated that whereas they may account for approximately 33% of heat loss of a conventional house, this may rise to as much as 40% for a house with greatly increased insulation. The thermal performance of windows and glazed doors may be significantly increased through the use of specially designed movable insulation in the form of curtains, blinds or shutters [12]. These may be manually operated and small scale for domestic application, or motorized and automated for institutional and commercial use. The thermal effectiveness of movable insulation is a function of both the thermal resistance of the matrix, and of the air tightness of the overall assembly. **Table 4.8.1.5-T$_1$** gives some typical thermal resistances of a number of thermal screening devices.

THERMAL RESISTANCE	
Screening Device	*RSI*
Lightweight mylar roll-up blinds	0.5-0.9
Quilted roll-up blinds	0.9-1.8
Folding shutters	1.8-2.0
Rigid sliding shutters	2.0-2.6

Table 4.8.1.5-T$_1$
Thermal resistance, *RSI*, of screening devices

Since the nighttime period, when the thermal screen would normally be in use, is as much as two thirds of the 24 hour period during the winter, the use of such screens could be expected to reduce heat loss by 30%-60%, depending on their efficiency.

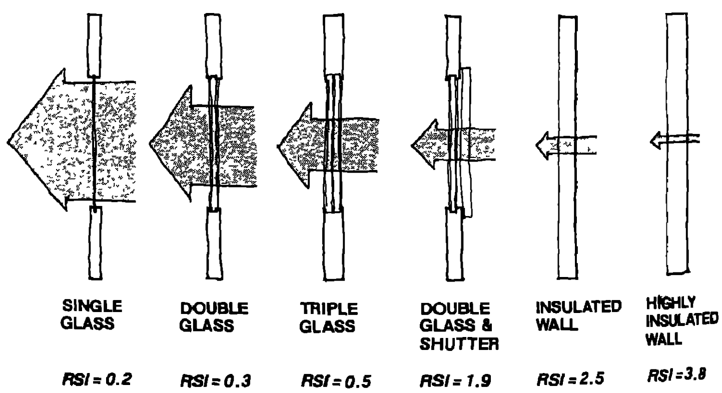

Figure 4.8.1.5-1
Heat loss characteristics of various types of windows and walls [13]

For further discussion of protective elements the reader is referred to **Section 4.9**, following.

4.9 Protective Elements

While, generally, we depend on the building enclosure to protect our activities from the forces of raw nature, many natural and man-made protective elements, particularly external ones, can create improved microclimates for the building These elements, such as wind breaks or architectural screens will be different according to orientation and climatic forces

4.9.1 Screen, Blinds, Shutters, Canopies

When considering the application of external devices it is important to differentiate between those buildings which have high internal heating loads, such as commercial and office buildings, and those which have high heat losses and low internal heating loads, for example, residential buildings The protective devices applied to such buildings, therefore, will be different.

To illustrate, generally speaking, the commercial office building requires some sun protection practically all year round even with colder temperature conditions However, the basic requirement of the residential building is that it be protected from solar gain in the summertime and receive maximum solar benefit in the winter In the following we shall consider these devices both externally as *exterior appendages to the building and as interior accessories*

4.9.1.1 Sun Controls

These can be effective on commercial buildings in latitudes experienced in Canada as they can provide protection from high summer sun and allow for passive solar heat gains in the winter

.1 Overhangs and Canopies: For residential application, a fixed horizontal overhang is frequently inadequate unless the window has a small vertical (sill to head) dimension because if it extends enough to keep out summer sun, it is often too wide to allow for maximum passive solar heat gain through the windows Many passive solar homes suffer from too much fixed overhang Extendable or moveable types are more appropriate These could be in the form of canvas canopies or self-storing awnings, such devices can be left to the design abilities of the individual architects for particular projects.

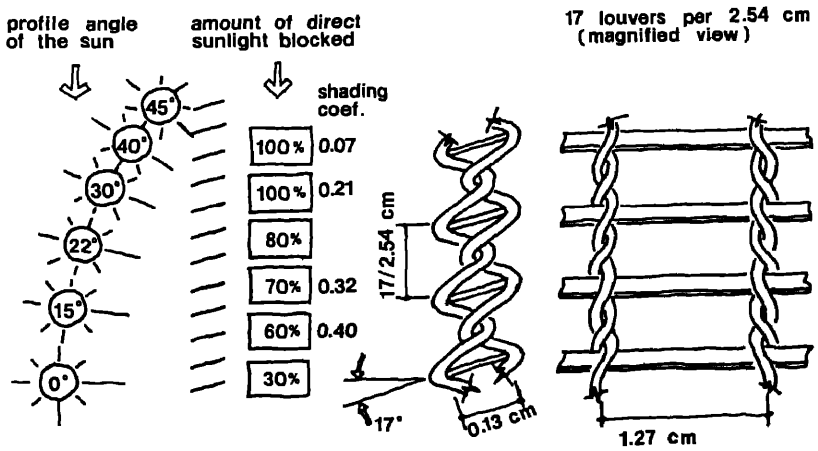

Figure 4.9.1.1-1
Sun penetration through a sun screen at varying sun angles

4.9 Protective Elements

.2 **Reflective Films:** In commercial buildings, exterior sun controls such as awnings or overhangs can be applied horizontally on the south facade of buildings but on the east and west orientation vertical louvres can be more effective However, in many applications for commercial buildings, the costs of such exterior devices are prohibitive when compared with the relatively new reflective window films These are applicable for commercial buildings because of the relatively low passive solar heat gain required in the heating season Such films, however, are not suitable for residential buildings in colder climates which require passive solar gain in the winter and protection from sun only in the summer Therefore, for sun control, residential buildings require devices that are either changed seasonally such as minilouvred, reflective, insect screens or adjustable external shutters, louvres or awnings

.3 **Venetian Blinds**· A popular addition to the office building is the venetian blind, often vertical on the east/west oriented windows and horizontal on the south facing windows Ref **Table 4.9.1 1-T$_1$** These blinds reflect the sun outwards in the summertime but allow for solar gain in the winter A new horizontal mini-louvre blind has been devised that reflects the passive solar sunlight onto the ceiling deep into the section of the room, thus providing for more daylight without producing glare to the office workers and reducing the need for electric lighting

*Type	Transmitted	Reflected	Absorbed
Light-Coloured Horizontal	0 05	0 55	0 40
Medium-Coloured Horizontal	0 05	0 35	0 6
White (closed) Vertical	0 00	0 77	0 23

*Blinds at 45° tilt with sunlight perpendicular to slats

Table 4 9 1 1-T$_1$
Properties of Venetian blinds [1]

Type of Glass		Solar Trans of Glass	Medium Horizontal	Light Horizontal	White Vertical**
Single	Clear	0 87	0 64	0 55	0 29
Single	Heat-AB	0 46	0 57	0 53	—
Single	Reflective*				
	SC = 0 30	—	0 25	0 23	
	= 0 40	—	0 33	0 29	
	= 0 50	—	0 42	0 38	
	= 0 60	—	0 50	0 44	--
Double	Clear	—	0 57	0 51	0 25
Double	Heat-AB***	—	0 39	0 36	0 22
Double	Reflective				
	SC = 0 20	—	0 19	0 18	—
	= 0 30	—	0 27	0 26	—
	= 0 40	—	0 34	0 33	—

*Shading coefficients (SC) under the reflective glass column indicate the performance of the glass without interior shading for the purpose of identifying glass types
**White vertical blind performance is rated for tightly closed blinds in conjunction with glass having a solar transmittance between 0 71 and 0 80
***Heat absorbing glass for outer sheet of glass, clear glass for inner sheet of glass

Table 4.9.1.1-T$_2$
Shading coefficients for venetian blinds.[2]

A disadvantage of all interior shading[3] accessories is that the heat absorbed in these devices is radiated into the building interior. If the blind or shade does not effectively seal the window the thermal insulative value is also minimal.

An advantage of Venetian blinds is that they can be tilted to provide maximum reflection of sunlight

4.9.1.2 Insulative Curtains, Blinds, Panels, Shutters

.1 **Daily and Seasonal Management:** Many new insulative products will soon be available to provide higher insulation values for residential windows Differentiation, however, must be made between daily management and seasonal management of the window

Seasonal management is the application for example, of a storm window to an existing window In many cases this application appears to be more cost effective than daily management with a shutter because it is on the window season-long. Daily management requires daily action by the occupants in order for it to be effective

.2 **Devices:** In addition to glass storm panels, sophisticated films such as a heat mirror will allow passive solar gain through but reflect infra red heat in the room back to the occupants, thus providing a higher effective *RSI*-value than the glass

Insulative window devices can be applied either externally, internally or inter-stitially, mounted between glass plates. They are fixed or moveable, they roll, fold up or are the rigid type which slide or are hinged More expensive systems such as beadwall with styrene insulation blown between glass plates are also being produced

Roll-down blinds made from layers of highly reflective materials with air spaces in between have a number of advantages including economical cost, ease of shipment (as compared with rigid panels) and they can be cut to size. The latter is of distinct benefit for retro-fit applications., **Figures 4.9.2-2 and 3.** They spread open

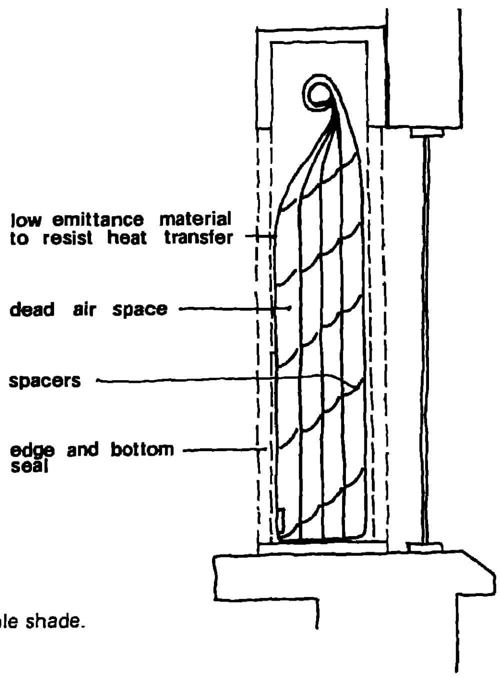

Figure 4.9.1.2-1
Insulating retractable shade.

either mechanically or by air temperature, as they expand they provide the necessary layers of air for insulation. One type consists of a roll-down polyester quilt with a reflective vapour barrier inside.

Several external rolling shutters are available, these however, have a relatively low *RSI*-value and are not well sealed from infiltration.

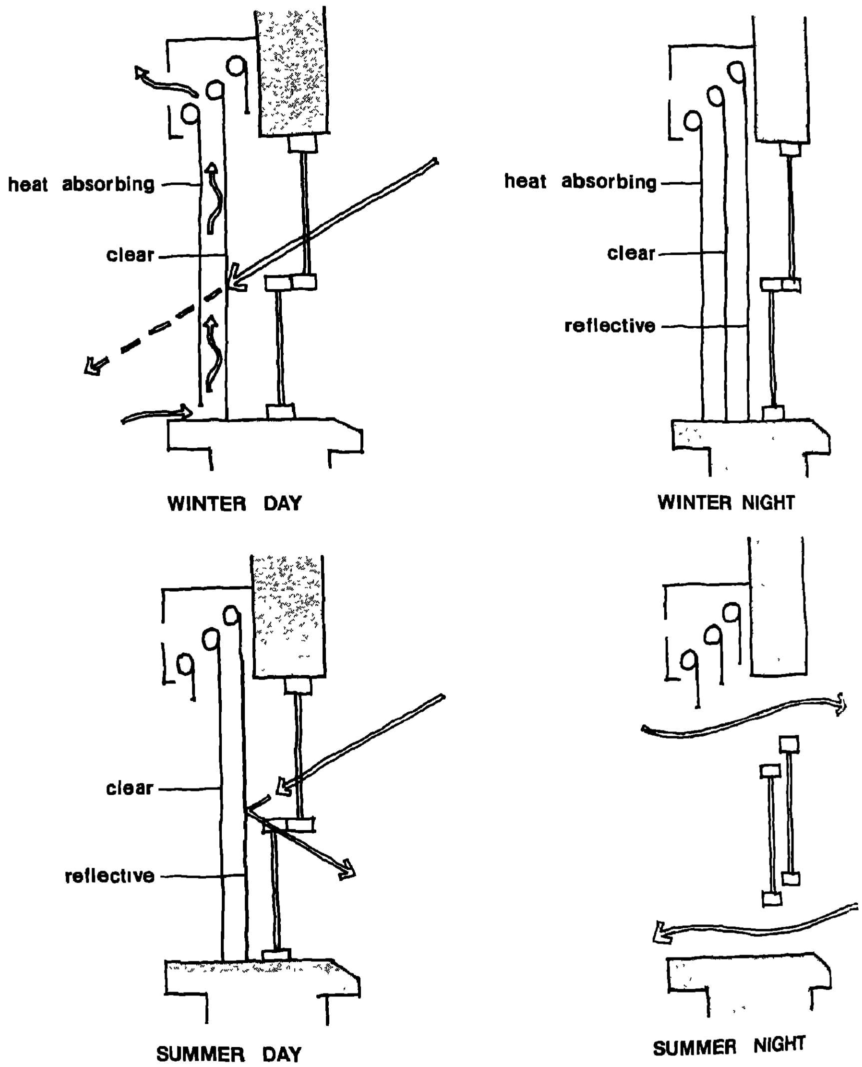

Figure 4.9.1 2-2
Multiple shade system

.3 Internal/External Application: Most of the insulated blinds are applied to the window internally, and this could cause problems of condensation or frost on the glass surface if they are not well sealed. Because windows are usually draped with decorative curtains, investigations[4] are presently being conducted to make such curtains well sealed with high insulation values. Insulation values for blinds and curtains range from approximately *RSI* 0.70 to 2.60.[5]

Rigid panels of high insulation value which can be pivotted or slid across glass surfaces diurnally are a less popular marketed product because of costs and installation However, they are applicable on a custom basis and can produce *RSI* values as high as 3 5 They must be sealed much more effectively than blinds in order to reduce danger of condensation and icing on the glass pane.

4.9.2 Rain Screen Principle[6]

In discussing thermal conductivity earlier in the Handbook (**Section 3.6.2**), it was noted that the higher the moisture content of a material, the lower will be its effectiveness as insulation For this reason, as well as others, it is important that exterior walls be designed so that the maximum amount of their mass is protected from rain penetration

The description of the rain screen wall design which follows indicates a method by which this can be achieved. Application of the rain screen principle also permits installation of insulation on the exterior face of the wall (with benefit in terms of thermal mass storage etc , **Sections 3.1.5 and 3.6.3**) and also provides wind protection for the building.

4.9.2.1 Causes of Water Penetration

Water can penetrate a building enclosure if three circumstances exist simultaneously, there must be water on the enclosure, a hole for it to pass through, and a force able to move the water through the hole When any one of the three circumstances is eliminated, the water will not penetrate the enclosure

It is often very difficult to eliminate all the holes through which water can pass in typical construction because of the articulated design of the building skin, the method of manufacturing the skin components, and the way they are assembled and caulked

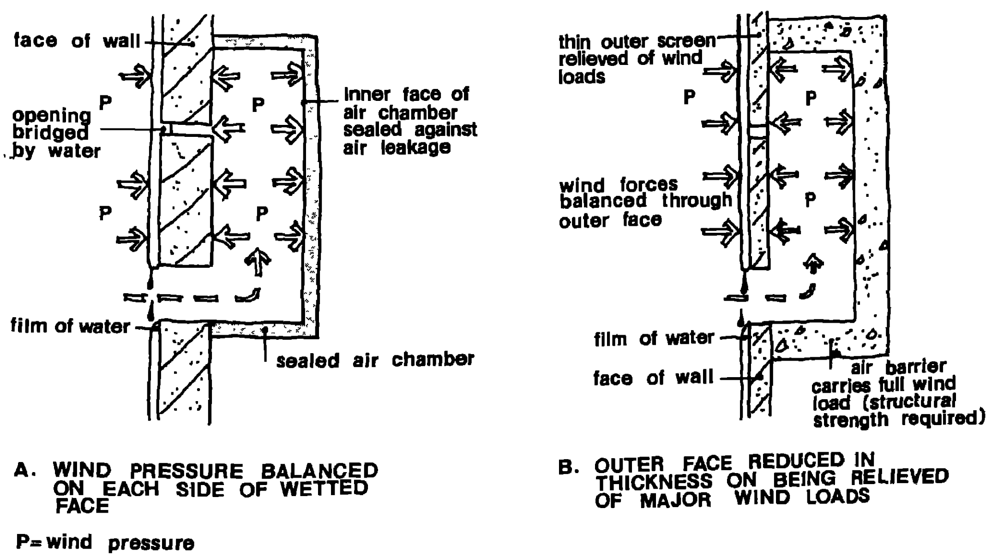

Figure 4.9 2.2-1
Wind pressure and wall sections.[7]

4.9.2.2 Rain Screen Wall Design

As the elimination of holes in the building enclosure is difficult if not impossible, it is therefore desirable to eliminate the force which moves the water through them

Obviously, it is not possible to stop wind from blowing, however, this force can be cancelled by applying an equal force acting outward at the opening in the enclosure. A film of water that would bridge the opening will thus be squeezed between the outward and inward forces and will not be moved inward or outward by either of them (Figure 4.9.2.2-1).

The basic principle of the open rain screen wall design is that openings are left in the face of the building which the water film can bridge. Other openings, too large to be bridged by water but protected by overhangs or sills, create the circumstance in which wind pressure is equalized on both sides of the screen Thus, no water will enter It is absolutely essential that the air chamber behind the rain screen be sealed on the inside in order to contain a pressure in the air chamber to counteract the wind pressure Therefore, the inner part of the wall behind the rain screen should be made as air tight as possible and the total area of opening in the outer part of the wall should be made as large as possible Insulation must be applied to control heat flow through the building envelope The rain screen protects the insulation from moisture and solar ultra-violet degradation

Provision should be made for drain-back to the outside of any water that may penetrate the rain screen into the air chamber due to unusual wind circumstances

A typical rain screen assembly is shown in Figure 4.9.2.2-2.

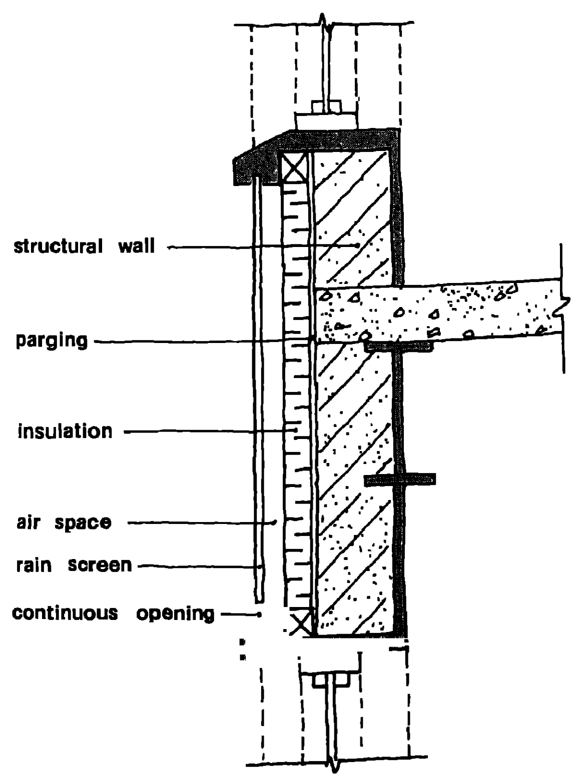

Figure 4.9.2.2-2
Rain screen assembly.

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5.0 Thermal Up-Grading of Existing Constructions and Built-In Energy Systems

Contents

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5.1 Factors Determining the Extent of Modifications and Retrofitting

Prior to embarking on an upgrading program in any existing building a detailed analysis of existing systems is required. When the ultimate goal of such a program is a reduction in operating costs, the yearly expenditure has to be evaluated. In most cases the operating costs include:

—cost of energy required to operate the building
—salaries for operating staff
—maintenance of existing systems.

This section will deal only with the analysis of energy used in a building which is the basis of thermal upgrading of existing constructions and built-in energy consuming systems To evaluate where and how the energy is used, a detailed energy audit is required, this is very similar to a financial audit performed by an accountant The commodity that the energy auditor is analyzing is the energy used in a building. The first step in an energy audit is the gathering of information

5.1.1 Energy Audit

The electrical bills can be obtained from local utilities. The information required is as follows:

—reading dates
—peak demand readings for that reading period
—peak kW and kV A
—electric energy consumption
—total costs
—*rate structure for the particular utility*

The fossil fuel consumption records can be obtained from local oil or gas suppliers The gas bills will reflect the gas used between the readings taken but the oil bills will reflect only the quantities delivered on a particular date, not the actual oil consumption. In some cases building staff keep logs reflecting daily oil or gas consumption.

After the bills are tabulated, the energy consuming systems must be listed and evaluated. Information is then required relating to existing systems and can be obtained from site inspections, record drawings and specifications

.1 **Electrical Equipment:** The electrical equipment existing in a typical building includes·

—lighting fixtures
—meters
—process or office equipment
—chillers
—snow melting equipment

Each type of equipment has to be evaluated to show power required to run each particular item, the operating hours and the season when it is used.

Analysis and summary of the above information will provide enough information to match the bills obtained from utilities. To obtain meaningful information, the monthly consumption, power peak and monthly costs should be matched. Matching the utility bills will show exactly where and how the electric energy is used. In most cases this will be done by computer programme.

.2 **Equipment Run By Fossil Fuel:** Fossil fuels are used to generate a hot water or steam heating medium. In a typical building the

heating medium is used to provide
—heating which is a function of outside temperatures
—preheat for ventilation air
—reheat
—domestic hot water
—kitchen hot water.

Again the fossil fuel consumption must be analysed on a monthly basis for each system and fuel consumption matched to the bills paid to a supplier and any available operation records

After performing the energy audit, each system should be evaluated for possible modifications or retro-fitting leading to thermal upgrading or reduction in energy consumption Each proposed modification should be evaluated for cost and benefit to the owner The energy audit and financial analysis will determine the extent of work needed to achieve required performance Such evaluation can best be performed by an inter-disciplinary team including architect, mechanical and electrical engineer and representatives of building operating staff.

5.1.2 Technical and Engineering Considerations

The energy audit provides sufficient information to establish the performance of existing systems Once completed, the effort can be concentrated on improvements to the present performance of existing systems

The first step is to ascertain whether or not the performance is comparable with the intention of the mechanical or electrical designer. A typical result of such evaluation could be a change in space usage leading to lighting level reduction and no changes in existing space air handling systems In such event the air quantities supplied to the space should be revised to match present lighting levels.

It is important to follow the space occupancy changes and accordingly change the system operation and, when warranted, the design It should be recognized that the systems were designed for worst conditions and for maximum requirements If the conditions or requirements change, the system design has to follow, otherwise the waste of energy can be significant

The next step is to revise the systems to incorporate technological improvements Obviously, a building ten years old does not include recently designed equipment which in most cases is likely to be more efficient Recovery of wasted heat in air or water systems of the past was rarely considered since most building owners were concerned with first costs and not with operating expenses which were negligible due to low energy prices.

Controls equipment and control strategies have changed dramatically Introduction of micro-computers and their application to building controls permits the close matching of building heating, ventilation and air-conditioning needs with a consequent reduction in energy wastage.

The efficiency of lighting systems was greatly improved with the introduction of energy efficient lamps and with new approaches to illumination such as the utilization of task lighting in place of uniform lighting levels which were provided regardless of functional requirements.

5.2 Methods of Modifying the Building Fabric

5.2.1 Introduction

Before tackling the problėms of improving the performance of older buildings—whether in connection with restoration or preservation—a thorough examination for deficiencies and assessment of problems must be made Care should be taken to determine the physical condition of walls, roofs, foundations and openings.

The construction techniques employed and nature of the building materials used must be thoroughly understood Potential points of infiltration around sash and frames at doors, or through the wàll, require careful inspection.

Earlier improvements, also, must be investigated—such as old insulations, often of the loose fill type without a vapour barrier, which frequently have compacted severely and become moisture-soaked blankets

Similarly, older types of batt insulation can settle and compress and the paper sheaths are often ineffectual as vapour barriers When there is also a lack of adequate ventilation, particularly in tight roof spaces such as those presented by the 'cathedral' ceiling of many mid-20th century houses, serious condensation problems and even internal icing can, and do, occur

Various criteria determine approaches to improving the building fabric, such criteria are based on the end uses of the space, permissible variations to original detail or general appearance, and the economic factors at play. To underline the variations possible, a brief description of the principal determinants is in order

5.2.1.1 Historical Restoration

Where buildings are to be restored to their original or significant state, that is to be exact in every exposed detail, improvements to the building fabric can be accomplished only in hidden sections or portions not open to public view In many cases this precludes improvement because solid walls do not permit insulation without increasing thicknesses, thus destroying relationships between trim and interior wall surfaces and disturbing apparent authenticity. Frequently only ceiling or roof spaces can be insulated resulting in only moderate improvement to the building's performance.

Historical restoration is the most demanding exercise and conditions for energy conservation are frequently far from ideal. It is important, therefore, to recognize this fact and where necessary ensure that the building's contents and use can withstand less than ideal conditions of comfort and control. Regrettably, this is at variance with demands by conservators of historic artifacts, such as furnishings, who demand more and more the ideal preservative atmosphere It is evident that this is seldom obtainable in an old building and we may have to continue to suffer the gradual loss of historic material unless it be confined to a museum specially constructed to favour conservation A compromise is inevitable in such cases.

5.2.1.2 Preservation

In the more liberal operation of continuing the active use of buildings of historical or architectural interest upgrading the performance of the building may be easier. However, one of the determinants will still be the relative worth of the historic architectural detail and its importance in the treatment of the building. Trim

and ornamental work may be essential to retain, but, where this is insignificant and sympathetic adaptations can be made, dimensional changes to the interior of the building may be accommodated, thus permitting the addition of insulation External changes to facilitate improvement of the outer surface are also possible

5.2.1.3 Reconstruction

Where historic buildings are reconstructed, any manner of improvements could be contemplated in the rebuilding To most, authenticity, so long as it applies to the finished appearance, is sufficient if detail such as trim and ornamental treatments and finished surfaces are accurate duplicates of the original or the original re-used. Authenticity here is only skin-deep perhaps, but, it suffices for all but a few incorrigible, and ever to be respected, buffs

5.2.2 Historical Precedent

Before embarking on modern improvements, it would be wise to recall some long-established building techniques worthy of re-examination or reassessment Some have a bearing on our current problems and considerations

5.2.2.1 Frost-proofing Basements

Old-fashioned practice in New Brunswick and other parts of the eastern seaboard coped with the problem of frost at the foundation level exposed above grade by building a double wall at this section Figure 5.2.2.1-1 Generally, construction below grade was not of the highest order, the foundation being constructed within a tight excavation, frequently laid dry or with very little mortar on the exterior It was of considerable thickness, up to 600mm (2 feet) or more, the interior surface more often neatly finished and thoroughly mortared From just below finished grade, a carefully constructed wall of about one half to two thirds the thickness was carried up to complete the foundation The interior was built up with an inner wythe, lining up with the wall below and having an air space behind This inner wall was often a single 100mm (4") thickness of brick laid in mortar, 100mm x 100mm (4" x 4") timber similarly laid or wood furring, lath and plaster

Further precautions, to help conserve the heat of rooms above and at the same time keep the basement areas at a relatively steady temperature, included floor filling similar to 'deafening' This comprised cross boarding set between joists near their lower edge, sometimes supplemented by fillings of plaster or clay and, on occasion, insulating materials such as tan bark, sawdust or wood shavings It was a bark filling used in the Grange (1817) in Toronto, which, absorbing a great deal of moisture, promoted decay of the floor timbers in that house, particularly above the wine cellar located below the entrance hall.

5.2.2.2 Wind Stopping

Infiltration, particularly around window and door frames, led early on to standard details in attempts to reduce this problem. Thus, wind-stops comprise a face piece nailed to the frame and built into

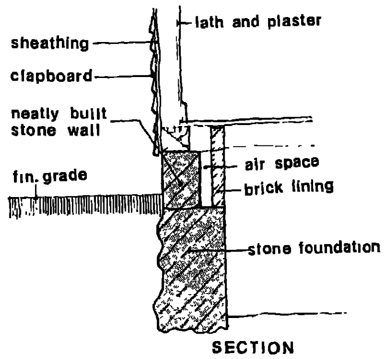

Figure 5 2 2.1-1
Basement frostproofing

the masonry or overlapping the timber structure. Frequently, and particularly in public and other important structures, facings to masonry buildings overlapped window and door frames, the frames set, as it were, in a rabbet in the wall Picked oakum, or tarred rope fibre, was the usual inner caulking, supplemented by pointing of the joint or in masonry buildings, the whole reveal being rendered with mortar.

Infiltration around windows was more often tolerated and compensated for by heavy curtaining at night when heat losses were most severe However, certain details were developed to help offset such problems. For instance, the checked meeting rail (or check rail) was devised in double hung windows separated by a parting stop. this was a decided improvement over the older and cruder form of fixed upper sash and lower sash meeting with flat surfaces.

The casement, opening in, is a particularly leaky assembly but usually when used in Quebec and, incidentally, also in Europe, the meeting stile has an interlocking knuckle joint, **Figure 5.2.2.2-1** sometimes augmented by similar configuration at the jambs This at least helps to control infiltration along the vertical edges of the sash but such an arrangement requires strong hinges as the sash are 'locked' together, usually with some force Additional hardware helps secure sash against frame—such as long cremorne bolts to top and bottom supplemented by latches or catches at the centre between the sash

Building papers acting as windstops below siding in frame houses are of relatively recent vintage Late 19th century and early 20th century papers were often rag felt types, usually grey in colour and reasonably durable because of their composition and weight. Gradually, asphalted papers, waterproof, but not vapour-proof, superseded these as windstops Today, rag has given way mostly to wood fibre with a consequent loss in durability.

A notable use of natural material as an effective windstop namely birch bark, is recorded in New Brunswick and is believed to be relatively common there. In the Goodine House above Mactaquac New Brunswick, this was used over wood undersheathing below the

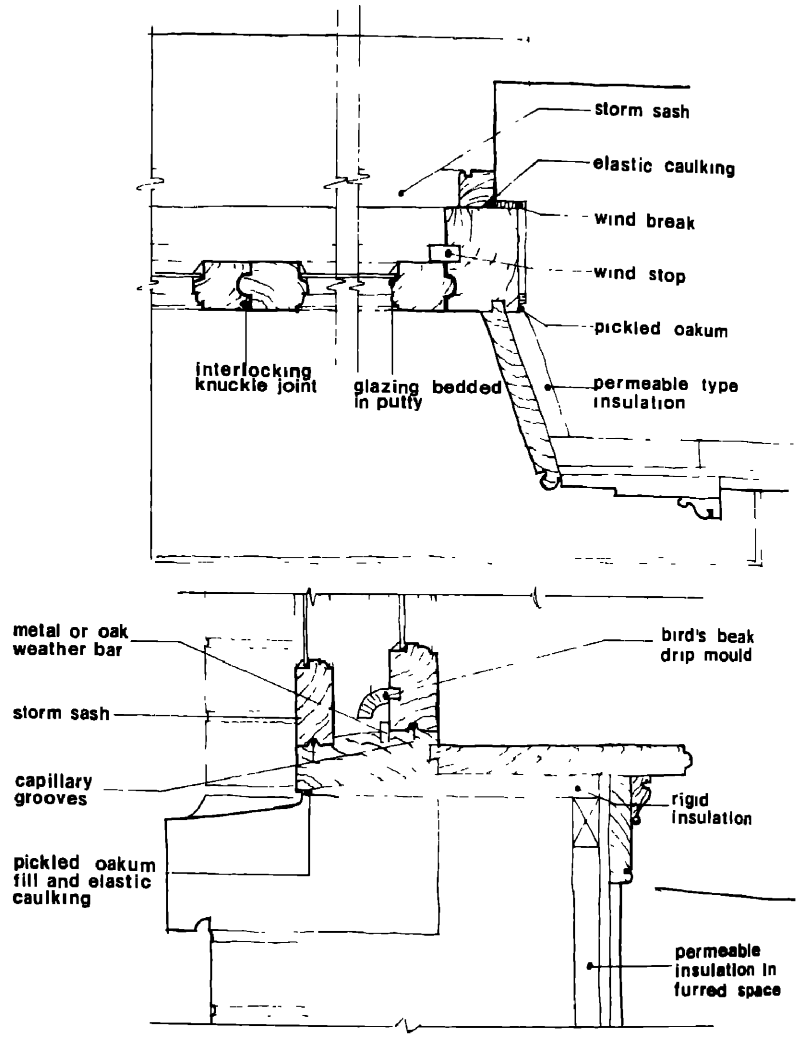

Figure 5 2 2 2-1
Casement window, wind stopping details

wood shingle wall finish This would have been very effective, and durable, although contributing to the flammability of the building in the event of fire

5.2.2.3 Cellular and Cavity Walls

Various constructions have been developed with a view to conserving material perhaps more than energy in the past, but their effectiveness in the latter might be described here The first concerns cellular construction in brick, exemplified by houses in the Prince Edward County area of Ontario and elsewhere, Figure 5.2.2.3-1. Here bricks are laid on edge in the characteristic early and mid-19th century patterning of Flemish bond, the bond bricks or headers roughly 210mm (8¼") long causing the upstanding stretchers some 60mm (2⅜") thick to have a cavity between of about 90mm (3½")

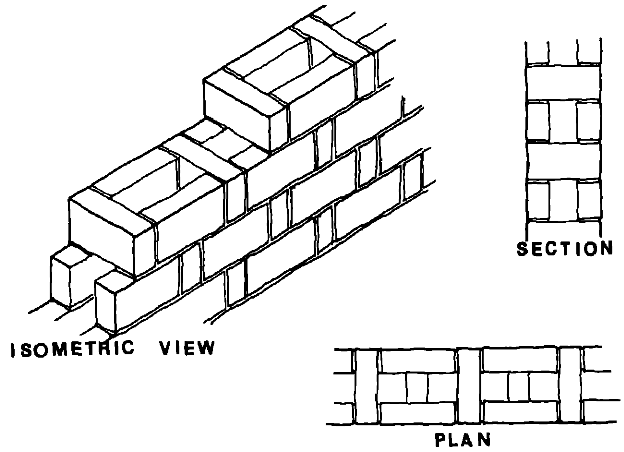

Figure 5 2 2 3-1
Cellular wall

These cells interconnect around the headers which, with the width of the cavity, would encourage convection currents thus lessening the wall's effectiveness as an insulator.

Cavity walls on the other hand can be very effective, not only as insulators, but also as rain or weather screens, (ref Section 4.9.2), their performance depending on equalizing pressure within the cavity to external wind forces to prevent penetration of moisture Many old solid masonry walls, particularly of brickwork, contain numerous voids especially where mortar was skimped between inner wythes or where frogs or depressions in bricks were laid downwards (the usual practice although generally contrary to most architectural specifications) Such walls, therefore act as a composite of cavity wall and heat storage medium, the latter to be considered later.

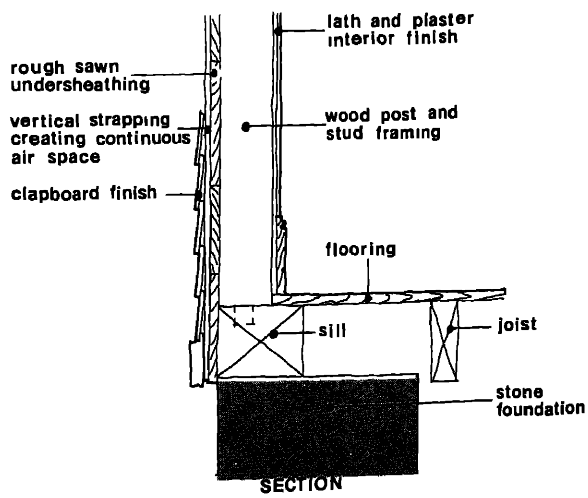

Figure 5.2.2.3-2
Wall construction, Macpherson house.

A version of the cavity wall principle, applied to a frame building, is to be found at the Allan Macpherson House constructed c 1826 in Napanee, Ontario, **Figure 5.2.2.3-2**. Here the timber frame was first sheathed in 25mm (1") rough sawn boarding, 13mm (½") vertical strapping applied and the finish of overlapping horizontal clapboard secured to this. Thus a continuous cavity behind the clapboard was created, contibuting to the durability of the finish by promoting ventilation behind it and acting as a windstop which effect was reduced only by cracks between the undersheathing This construction, improved with insulation board, asphalted building paper and insulation between wall timbers, has been the basis for improvements to many frame buildings in Ontario

5.2.2.4 Natural Insulations

Natural insulations refers to products using or created from natural materials Most, if not all, of our older insulation can be included in this description The basic requirement was a substance of cellular form, or was an insulator by nature and when placed was also effective by forming trapped air spaces Moss, wood in solid sawdust or shaving form or bark, especially cork in solid or granulated form were the most effective and easily obtained Similar materials such as feathers were too precious to be used in other than eiderdowns and similar comforts, and how effective or durable the fluff of milkweed pods can be is not known

In most instances where dry heated interiors occurred, such as those with stoves, hot air furnaces without benefit of controlled and effectual humidification or those using hot water or steam heating systems, such insulations without vapour barriers may suffice But as soon as normal internal humidification is practised, that is above 10% RH, serious problems develop, best exemplified in an Ottawa example. This was a wing, added to an older house in 1944, and comprising a 100mm (4") stud wall (50mm x 100mm at 400mm spacing) finished on the exterior with cement stucco on metal lath the lath being applied directly to the studs Gypsum lath and plaster formed the interior finish and the cavities in the wall were filled with powdered cork In 1961, (seventeen years after construction) the wall was opened up during renovations to discover that 10mm to 25 mm of the outer edge of the studs had rotted off caused by condensation of vapour inside the outer skin after it migrated through the insulation from the heated interior of the building

The absorptive nature of most natural insulators makes it essential to provide vapour barriers to the warm side, particularly if timber, always vulnerable to decay, is used in construction as is the case in most older buildings Vapour barriers are often defective or absent in many older types of insulations, equally destructive in many amateur—and some so-called professional—installations, the vapour barrier is incorrectly reversed performing on the colder side as a vapour trap The same problem occurs when excessive cooling is practised and the insulation is required to act in reverse sometimes causing breakdown of composition and severe internal condensation leading to staining of internal finishes and even leaking into the interior

5.2.2.5 Shutters

One of the most effective domestic details used in the warmer parts of Canada is the window shutter In summer this can eliminate the need for artificial cooling if used effectively to shade the window from the sun Ventilation can usually be maintained when the shutter is closed as most are louvred designs, sometimes referred to historically as Venetian blinds Occasionally the louvres can be manipulated to shut completely or remain open and permit some light to enter. Thus the sun is kept away not only from the interior, but the shutter is far more effective than internal blinds or curtains in shading the glass itself and preventing the greenhouse effect of sunny sash

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5.2.3 Types of Construction

Buildings can be grouped generally into their basic constiuction, configuration and ultimate use for the purposes of discussing improvements. However, it is construction which will govern heie, and variations noted as may apply to other considerations including an old building's appeal to other than economic considerations

Masonry buildings form the largest group of structures difficult to improve Timber buildings vary from those of solid wood, relatively effective in themselves by the nature of their material, to framed buildings easier to upgrade in most instances Some special construction methods have particular problems. Understanding the construction of a building and the performance of its components is essential too little cognizance is taken of these facts and many merely ineffectual to distinctly damaging results are obtained at great cost It has to be recognized also that some old buildings are worth preserving which can never be efficient in conserving energy; less comfort or more clothes may be a more sensible answer

The order of concern essentially, will be according to the parts of the building, beginning with walls, followed by openings and closing with roofs The first differs between the type of construction whereas other aspects are usually components common to old buildings and often have similar problems which can be explored together

5.2.3.1 Modifying Masonry Buildings

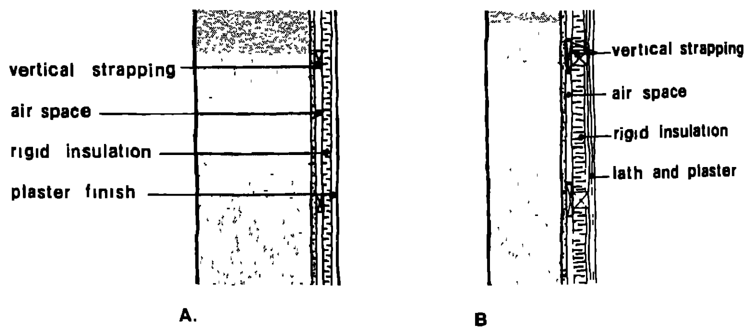
One particular caution should be mentioned in dealing with masonry buildings, namely, that walls constructed of relatively porous brick or stone with lime mortar appear to allow the free migration of moisture, especially in the form of vapour, through the wall in either direction—depending on relative conditions externally and internally. To inhibit this free transfer of vapour in one direction can cause a buildup of moisture within the core of the wall causing breakdown of the mortar and literally decay of the masonry. This condition has been witnessed in the north-eastern United States where vapour-proof sheet-type insulations have been applied directly to the inside of old masonry walls or on masonry plastered without a furred space

By the same token the filling of a cavity, formed by furring, with a vapour-proof or impermeable expanding foam type insulation has a similar effect and such insulations should not be employed. Not only do older masonry walls absorb more, from rain as well as atmospheric or internal humidity, but they transfer this and dry out

almost like sponges. The wick action of old brickwork and foundations of stone masonry is a well-known phenomenon and often a problem in other ways

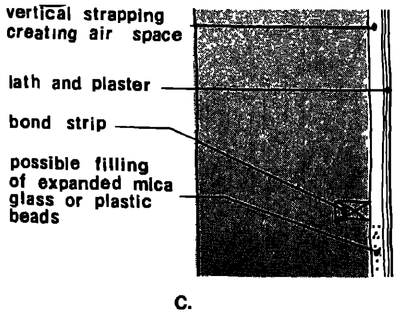
In the case of a solid masonry wall with plaster applied directly to the interior face and an interior demanding restoration, no improvement to insulation should be attempted Consolation should be had in the amazing heat storage capacity of a thick masonry wall, particularly of brick (witness the radiant evening warmth of such a wall sun-soaked during the day), in its contributing warmth from summer storage during early winter and its contributing cooling to the first warm days of summer The 'sweating' (condensation, in fact) of masonry walls, and even plaster over furred spaces, when spring's sudden warmth occurs demonstrates this too and confirms what has been said earlier about thermal capacity in Section 3.1 5

Should the wall be furred out with strapping the cavity may be filled with a granular cellular type insulation of the bead type poured in from the upper level or roof space, taking care to stop up all holes into floor spaces and elsewhere in the process Expanded mica and small plastic or glass beads can be employed to effect some small improvement **Figure 5.2.3.1-1**. Alternatively, it can be filled with a new non-vapour-proof or sufficiently permeable expanding type insulation to guarantee that vapour migration is not inhibited unduly In any case, sealing of the open ends of furred spaces at floor levels at the basement if exposed and similarly in the roof space, will help to confine convection currents and make the air space more effective as an insulator



Plans of brick walls showing alternate methods for installing rigid insulation

Section showing interior furring or "scotch method" with possible improvement



Plan of brick wall showing [illegible] frame wall insulated

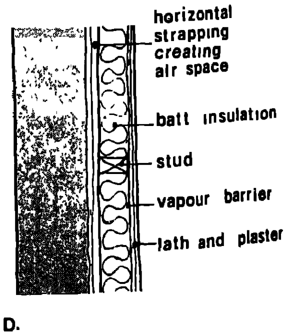


Figure 5 2 3.1-1
Masonry wall improvements

Should it be possible to allow modifications to detail, such as building-out trim to accommodate extra wall thicknesses, then superimposed insulations can be applied to the interior—always allowing an air-space between masonry and insulation, however, although this can effectively be reduced to 12.5 mm in the rebuilding. The choice of insulation will be determined by the thickness which can be allowed and its effectiveness. If it is possible to redesign the interior trim or finish completely, and the loss of space is not critical, internal stud furring insulated in the conventional way with glass or mineral fibre batts and internal and/or additional vapour barriers can be used, keeping always in mind the need for a minimum air space behind the insulation

Where the original exterior face does not have to be retained, the application of external insulation may have distinct advantages in older masonry buildings—particularly as the large mass of the walls can serve as heat storage, ref. **Section 3.1.5**. Modern technique can be employed here provided the precaution is taken to maintain an air space on the external side as noted for interior insulation. Sheet insulations can be applied over furring, the surface protected by prefinished metal claddings or similar attractive and durable materials.

Where walls face east in the eastern part of Canada, masonry has often been damaged by moisture penetration and freeze-thaw cycles in early winter easterlies The only remedy in such circumstances used to be covering with sheet metal (as in Quebec) or rendering with roughcast or lime stucco and, more recently, with cement stucco The last, though waterproof, was often incompatible with the parent masonry and hence often caused further breakdown Creating a weather skin with attendant air cavity would be of benefit, and the ideal condition would be achieved by applying insulation over a furred space, with the cladding separated from the insulation by another air space so that it can perform as a weather and rain screen

In some cases the exterior cannot be renovated by applying a new external skin and, at the same time, the interior brick surface often present in converted warehouse and industrial space is much admired, especially when cleaned down, 'au naturel'. Here exterior walls are usually load-bearing and of considerable thickness and although inefficient as insulators perform, in compensation, as a heat storage medium. Many Victorian terrace houses stripped to their naked brick party walls share the direct warmth of their neighbours; it is interesting to cogitate upon future claims for dependency. However, end walls exposed to the elements must be treated properly as these usually have enormous surface (allowing considerable, often rapid, heat transfer) relative to the floor area and volume of the building.

5.2.3.2 Treatment of Special Masonry

Some special structures should be mentioned. Even though these are not of common occurrence they are found in various parts of the country and relate usually to historic buildings. The first comprises adobe or unburnt clay brick or block. This was a popular building material in southern Ontario in the early and mid-19th century and somewhat later elsewhere. The material is usually a clay, often of a

slightly silty nature which resists cracking on drying, and usually is reinforced with chopped straw or similar binder The Helliwell House of c 1838 in Todmorden Mills (East York's Centennial project in the lower Don Valley of Toronto) is typical of this building method The blocks were air-dried and laid with mud mortar, two blocks or some 400 mm thick to exterior walls, the outside protected with lime roughcast, the interior plastered directly The nature of the material provides an ideal heat storage medium of relatively slow transfer characteristics maintaining relative comfort and equable conditions Rammed earth would have similar qualities Both materials might be promoted for low cost housing if codes would allow

Another material—the poured wall—actually, weak lime concrete, came into fashion after Orson Squire Fowler's publication of the House for All or the Gravel Wall and the Octagon Mode of Building in 1849 Octagons from about the mid-19th century are frequently built of this material in eastern Canada and an example of an 1858 cross gabled house of the Gothic Revival survives in Port Hope Examination of the damage wrought to this poured house by a negligent insulation contractor reveals the wall to have been a much honeycombed matrix of beach, or water-washed gravel, sand and lime, apparently mixed and placed in relatively dry condition (i e — with a low slump) between wooden forms The honeycomb provides a natural insulating quality, the bulk of the material some heat storage capacity In this particular case insulation was a poor investment, for even after supposed filling of interior cavities between interior furring, many sections were found without insulation

5.2.3.3 Solid Timber Structures and Their Improvement

Because of the cellular nature of timber, its insulating characteristics are relatively high for a structural material and in historic buildings may be adequate without further modification Log buildings or those of en colombage, (i e constructed of a timber frame with solid timber infilling between posts), can be found from coast to coast in Canada—marking the paths of the fur traders They are usually deficient mainly at joints between wood members or parts requiring various methods of chinking to prevent air leaks or infiltration This can now be improved in log buildings by adding insulating plugs or backings to replace moss or wood wedges before the traditional lime mortar chinking is applied to exterior and interior faces Again, if the wall is a thinner lumber, such as vertical plank, interior insulation may be advisable so long as this can be part of alterations compatible with the old building

Certain timber buildings, namely those of sawmill plank construction with 25 mm to 50 mm thick by 100 mm to 200 mm wide stuff usually laid offset 15 mm ± in alternate layers, are frequently finished externally with a stucco rendering, smooth or more often roughcast, the interior plastered directly, the finishes keyed to the structure. Such buildings, like those constructed of log, had relatively good insulating characteristics and it may not be economically feasible or practicable to alter them to ensure better performance The same could be mentioned for cordwood construction where short logs are laid in mortar across the thickness of the wall

5.2.3.4 Framed Timber Buildings and Their Improvements

The buildings most easily treated, and most satisfactorily dealt with are those constructed of timber frame where the cavity between members is without any filling such as brick nogging, stone (colombage enpierrotte) or wattle and daub Many old frame buildings are very crudely finished externally, with the clapboard nailed directly to the frame, especially in southern Ontario where winters are warmer than other parts of Canada When the cladding shrinks, cracks or decays, the wind literally whistles through, the heat escaping at a prodigious rate, compensated for only by an enormous supply of fuel such as wood or coal for stoves. Most heating systems cannot cope with the rapid and often extreme fluctuations involved In colder climates such as the Atlantic Provinces builders early on learned to employ better building practices and used undersheathing below cladding, but still leakage was often severe

In essence, the main problem can be solved by filling the cavities between timbers with insulation of the vapour proof type Some expanding type foams can be injected into the wall cavity between studs and between horizontal members such as girts and plates or diagonal braces, but many of these lose their effectiveness by not completely filling the cavity, by shrinking or by not adhering to studs Such materials are generally superior to loose fill insulations of the non-vapour proof type which often promote timber decay by getting soggy with condensation. Furthermore, blown-in insulation or poured insulation often packs down over the years leaving a void near ceilings, the compaction increasing with every slam of the front door

If the interior wall surfaces are to be replaced then a conventional glass or mineral fibre batt with integral vapour barrier, supplemented by a plastic film vapour barrier, is the most effective When the interior wall surfaces are of good quality, and in order to avoid disturbing the trim, the work can be done from the outside, particularly if the exterior has to be replaced. In this event, friction-

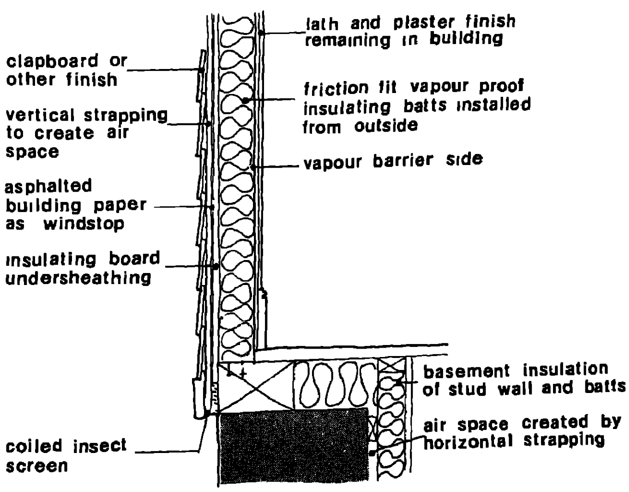


Figure 5 2 3 4-1
Wood frame construction, improvements

fit batts can be placed between wall members, and the outside reconstructed as a modified Macpherson House method, including insulating board undersheathing, asphalt building paper, strapping and cladding Figure 5.2.3.4-1. The vapour barrier in this case cannot be absolute, but the permeable outer layers will prevent leaking vapour from being trapped to cause condensation

Structures with masonry veneers over frame can be dealt with as with ordinary timber buildings Filling the cavity between the veneer and the undersheathing, however, is generally not advisable as this destroys the weather screen effect of the veneer and in extreme cases may dislocate this outer facing. Furthermore, the amount of insulation which can be placed in the cavity may not prove of much benefit even in the best of circumstances

5.2.3.5 Basement Insulation

Insulation of the frost range, that is, where frost penetrating the ground affects the foundation, can be dealt with by improvements according to modern practice This can be done by external or internal treatment, the latter by means of a furred space to prevent trapping moisture in the wall In buildings where cellars are to be restored, insulation has to be applied externally, preferably over a waterproofed outer rendering applied to the foundation

5.2.3.6 Improvement of Openings

Adequate caulking between frames and masonry openings can help to reduce air infiltration substantially Modern methods are frequently employed to replace mortar fillings, subject to cracking and shrinkage, with elastic caulking compounds

In frame buildings, wind stops as part of the frame assembly, are important and may be combined with a blind stop in reconstructing exterior finishes Building paper gaskets and metal bands serving as windstops also improve performance

Modern techniques of weather-stripping can also be applied Treatment of windows has been discussed previously In preservation, new assemblies can incorporate improvements without substantially altering appearance.

Important features to consider are double glazing and storm doors These are most effective if constructed of wood, fitted neatly and provided with foam plastic gaskets or similar seals Storm windows can be simplified versions of the older sash pattern of the window taking care, however to have divisions, where these occur, coinciding with those below. There is nothing more disturbing in appearance than a storm window divided down the centre superimposed on a sash three panes wide Storm doors, again, can be simple board or plank designs, or glazed if facing south and passive solar collection is the intention

Inner vestibules, perhaps removable, are another solution to winter draughts Likewise, the construction of an exterior porch compatible with the design of the building may be worthwhile improvement, especially at much used entrances exposed to the weather.

Improper glazing, particularly of wood sash, can be not only a cause of deterioration but also a great source of infiltration. Often

glass is replaced carelessly in repairs and backputtying or bedding the glass in putty or glazing compound omitted so that the face putty becomes the only seal In this malpractice, loose and rattling window panes invariably result and the outer seal breaks down Infiltration and sash decay follow as condensation forms on the inside and runs into the glazing rabbet Glass cannot be fitted tight to the sash a bed of putty or glazing compound, however, forms the perfect seal When the face putty does break down, as in cases of poor maintenance, at least a second line of defence is provided in the backputtying procedure

5.2.3.7 Roof Spaces

Conventional methods of insulating roofs or ceilings below roof spaces generally apply to older buildings Care must be exercised, however, to maintain air circulation over insulation and below roof decks where the structure and finish are timber This can be achieved by adequate venting near the ridge and near or through the eaves in buildings with pitched roofs

Again vapour barriers are important between warm spaces and insulated areas There can be a continuous sheet, such as polyethylene film, but care must be taken to cover the whole sheet, even where it rises over a joist, with insulation. Otherwise the exposed film, with no insulation blanket, will act as a vapour trap to provoke the decay of the joist Alternatively friction fit batts may be used for the purpose, the vapour barrier set downwards to the warm side.

One particular form proves especially difficult to insulate, namely the quarter or half storey with sloping ceiling attached directly to the underside of the rafters Here more efficient rigid insulations of the vapour proof type can be slipped down from the roof space formed by the collar ties. An alternative, if permissible, would be to fur down and insulate the sloped section, thus leaving the rafter space for air circulation Flat or low sloping roofs using wood joists pose another potential problem which has to be overcome, namely to ensure ventilation over insulation applied from below, and between the insulation and the impervious roofing layer generally used such as bituminous material or sheet metal It may be necessary to construct a new venting system to ensure this. Frequently insulation, as in modern practice, is combined with roofing Care here has to be exercised to maintain the integrity of the roofing membrane as a waterproof skin: hence, insulation is often applied over this (with a supplementary weathering or wearing surface) to obviate cracks resulting from shrinkage or thermal movements of the insulation

5.2.3.8 Improvements to Other Details

Open fireplaces, often present in historic buildings, pose a serious cause of heat loss when not in use The old method was to use a chimney board to close them during such periods. This may not be reasonable in an historic display. It would be wise to consider discreet damper installation to help control cold down draughts. Standard cast iron dampers can sometimes be used, but steel units may have to be fabricated to fit special conditions.

5.2.3.9 Alternative Energy Sources

Ample opportunity exists for applying modern technology to reducing energy costs in older buildings Most downtown building of the 19th and early 20th century in smaller centres has a high proportion of flat roofs free to the sky and suitable for locating solar collectors Many of these buildings constructed in unbroken fronts, like those of Walton Street in Port Hope, are relatively low energy consumers in any case, since only front and back walls are exposed in most instances and a large area and volume is enclosed within a relatively small wall surface

In some instances, restoration of early masonry buildings precludes insulating the walls Several houses in the Niagara Peninsula area of Southern Ontario are barely 200 mm of brick plastered directly on the inside giving little capacity for heat storage and cooling off rapidly in winter in high winds However, in one instance the incorporation of electrical heating cable in the plaster below the chair-rail is being considered in a house, this resistance heating will be coupled to a wind generator so that 'twill be an ill wind that blows no good '

5.3 Methods of Modifying The Built-In Energy Systems

5.3.1 Introduction

Existing energy systems can be made more energy conserving in two principal ways—by the up-dating of their design and by modification of their operation. A summary of opportunities and recommendations follows

5.3.1.1 Design Up-date

Opportunities for energy conservation in this category relate to heat recovery, artificial illumination levels, domestic water supplies and design of the building envelope.

.1 **Exhaust heat recovery**: Heat in air exhausted from the building can be reclaimed and recycled to heat sinks such as outside air intakes, domestic hot water preheat and building space heat supply.

Exhaust heat recovery can be achieved by means of air to air thermal wheels, heat pipes, glycol run around systems and central or local heat pump systems Heat pump systems provide reclaimed heat at higher temperature at the expense of electrical or mechanical power input

.2 **Grey water heat recovery**: This involves the separation of warm waste water (sinks, baths) from cool sanitary wastes (urinals, W.C 's) by additional plumbing risers Heat can be extracted by an indirect transfer system for recycling to building heat sinks such as domestic hot water preheat

Employment of central or local heat pump systems will produce reclaimed heat at higher temperature grade.

.3 **Artificial illumination levels**: Many existing buildings have excessive levels of electrical illumination. The use of each building space should be reviewed and new objectives for lighting levels for general illumination and for background plus task illumination established The designer should.

—Develop new lighting floor plan patterns and remove surplus lighting fixtures The disconnection or rearrangement of ballasts should be designed to minimize electrical losses
—Consider replacement of used fluorescent tubes with higher efficiency tubes
—Adopt low background plus task illumination wherever practicable and appropriate for room function
—Review zoning and switching arrangements to allow more economical programmes of light switching in daily use
—Consider central control by zones of open areas and private office switching at individuals' discretion
—Co-ordinate zoned switching arrangements with automatic modulation of lighting levels for demand limiting and energy conservation

.4 **Domestic water supplies**: Conservation in the use of hot and cold water supplies is highly energy effective. Measures that should be considered include the following:

—the use of flow limiting restrictors at all water outlets to obtain minimum acceptable rate of flow; for routine hand washing purposes installation of a single outlet faucet with 37°C water supply
—adjustment of flush valves and cisterns for WC's to obtain minimum acceptable flushing action
—shut-down of automatic flush tanks for urinals at night
—installation of fine spray aerators at faucets and shower nozzles

—shut-down of domestic hot water circulating pump at night and prevention of thermo-syphonic heat losses from storage tanks

.5 **Building envelope**: The poorly sealed building envelope will allow uncontrolled air exfiltration and infiltration which are major causes of heat and vapour losses and are major energy consumers

The following locations should be examined and appropriate remedial measures taken as indicated

—air and vapour membranes in the envelope construction membrane effectiveness should be improved wherever practical
—windows sealing arrangements should be checked
—ducting and piping shafts any open ended situations must be sealed
—shut-off dampers on all ductwork intakes, exhausts to outside air damper operation and seals, particularly on intermittent systems, require careful inspection
—elevator penthouses seals to machinery openings and smoke vents should be improved as far as practicable, also should be checked, stair shaft smoke vents
—frequently used entrances double doors with deep vestibules or revolving doors should be installed
—insulation in addition to upgrading insulation in walls, windows and roofs, consideration should be given to additional insulation to piping and ductwork where losses and gains are not energy-advantageous to the surrounding space
—thermal balance· an assessment should be made of building transmission losses and internal heat gains

5.3.1.2 Modifications of Operation

Opportunities for energy conservation in this category are as follows

.1 **Smoothing the electrical demand peaks**: First of all it is necessary to determine the major electrical demands of the building e g lighting, HVAC, laundry and kitchen systems Consideration should then be given to demand sharing by modulating lighting levels in non-critical areas, by switching off non-critical equipment during known cyclic peaks and by careful load selection for electrical equipment to avoid oversizing Peak demand monitors should be installed with pre-programmed automatic off-loading and provision for central manual switching for major installations

.2 **Reducing the ventilation demand**· In many air conditioned buildings the total air circulation is set throughout the year by cooling requirements which occur for only a few days in summer Air supply should be scheduled throughout the year in relation to seasonal conditions To this end outside air proportions may require adjustment to match periods in peak summer and in extremes of winter Supercooling the air supply on peak summer days will reduce the year round air circulation

Energy-conserving illumination levels and improved solar shading and reflection in summer will lessen the ventilation load and existing ventilation rates should be reduced accordingly

.3 **Removing system overpressures**: For energy economy, all systems should produce or utilize energy at the least pressure at which those systems will operate satisfactorily. All pressurized systems serving the building should be reviewed for possible overpressure; this includes fan systems, steam generators and hot and cold water pumps The necessary adjustments should be made to obtain minimum satis-

factory working pressure Terminal pressure reducing valves installed on steam equipment will help to reduce steam consumption, high condensate temperature conditions and flash steam losses

.4 **Tuning the temperature and humidity controllers:** The function and optimum settings of all temperature and humidity controllers for both local and centralized systems in the building should be reviewed. The best theoretical settings for energy conservation can then be determined and the controllers adjusted to levels which are 'barely acceptable'—if necessary, by trial and error

It should be noted that optimum settings for room thermostats are not necessarily the lowest acceptable settings. Systems which provide year-round cooling, such as interior variable volume systems, are usually more energy-conservative when room thermostats are set at the high end of the acceptable temperature range.

.5 **Operating hours:** Since the most energy-conserving system is one which never operates, it follows that minimizing operating periods will reduce energy consumption. This entails a review of the functional occupancy of the building and the optimum operating times for all building systems It will then be possible to determine the best theoretical operating times by day and by season and adjust to acceptable levels, if necessary by trial and error Where possible, advantage should be taken of building thermal inertia by overnight and weekend shutdown of HVAC systems

5.3.1.3 Energy Management Centre

Many buildings do not have central monitoring and instrumentation of energy systems nor the facilities for remote switching and adjustment of critical equipment Often, the experience and analytical ability of the operating staff is not adequate to the task of interpreting the building energy data and of optimizing system performance Thus, when an energy management centre is considered the question of availability and cost of competent staff must be added to the financing of the new installation. When microprocessors are included with the management centre the systems can be extensively automated to reduce the number of manual functions However, in a complex building such as a hospital, the parameters which affect energy consumption are frequently changing and the human ability to analyse and to optimize new requirements remains an important staffing consideration with associated expense.

5.4 Measures to Prevent Rapid Obsolescence of Designs

5.4.1 Passive and Active Measures

Obsolescence will be determined by the suitability of buildings and their incorporated systems for adaption to changing energy supplies A building that has no requirement for non-renewable energy is relatively immune to absolescence

The previous section classified energy into categories ranging from 'hard' to 'soft' demands and high or low grade form. This chapter is devoted to qualitative and quantitative energy processes and the effect energy supply and use has on building obsolescence

The hard energy requirements are usually dependent on electricity supplied by utility companies In the course of performing work, the energy is degraded to the lower potential form of heat The excess heat can be reclaimed to partially meet the thermal demand or it can be expelled as waste heat As a consequence of the latter, electricity or fossil fuel is required to generate heat for the soft thermal loads

Conservation of energy in all three categories and effective energy recycling from higher to lower grades are the key ingredients in delaying the process of obsolescence in buildings The following are the principle approaches which should be taken, in various forms

5.4.1.1 Passive Methods

Passive methods will reduce energy demand by the following means:

—installation of thermal insulation to reduce the loss of heat during the winter and the gain of heat in the summer, the optimum point exists when the sum of all design heat losses at design condition is less than the sum of all heat gains

—arrangement of glazing for maximum natural lighting effect, minimum heat gain in the summer and maximum solar penetration in the winter, windows are the most cost effective solar energy collection system available

—optimum utilization of energy such as the rationalized use of lighting and domestic hot water, these are most effective methods of conservation (Ref Section 5 3)

—relaxation of performance criteria such as controlling temperature and humidity within wider comfort ranges reduces demand rates thus smaller energy systems are required

5.4.1.2 Active Methods

Obsolescence will be avoided if systems are designed for maximum energy efficiency and adaptability relative to energy source Consideration should be given to the following

—design of total energy systems suitable for utilization of the widest range of energy forms (The prudent selection of an energy transfer medium is the essential feature that leaves the options open for changes in energy supplies For example, an electric resistance heating element is subject to complete absolescence with only minute changes in the condition of the electricity supply A hot water radiator, however, supplied from a boiler could be made to function with all forms of energy capable of heating the water)

—design of central systems that encompass the operation of the entire building as a control element

5.4 Measures to Prevent Rapid Obsolescence of Designs

—inclusion of cost effective recovery systems and utilization of all 'free' sources of energy such as solar energy and wastes such as garbage and sewage

—awareness that buildings are dynamic machines that serve specific functions for only very limited periods, this should lead to the understanding that new buildings should be designed for planned primary and secondary life-cycles with obsolescence considerations incorporated into all phases

5.5 Consideration of Alternative Energy Sources for Buildings

5.5.1 Quality of Energy Requirements

The quality of energy requirements within buildings can be classified into three categories:
—electrical
—motive
—thermal.

5.5.1.1 Electrical Energy

Electrical energy is a 'hard' demand because there are no source alternatives, it is required for lighting, business machines, controls and other uses Since individual electrical generation has rarely been justified economically, electricity is usually supplied by the local utility company.

5.5.1.2 Motive Energy

Motive energy is required to operate all building ancillaries, elevators, ventilation fans, air conditioning fans, heating fans, and mechanical refrigeration equipment With rare exceptions, the motive energy demand has been supplied with electricity provided by the local utility company The inevitable removal of monopolistic electrical generating privileges from the utility companies has encouraged the reassessment of other sources for the motive energy demand components

Co-generation of electricity and the use of mechanical drives such as internal and external combustion engines can be expected to become increasingly popular

5.5.1.3 Thermal Energy

Thermal energy is required for heating in order to maintain given building temperatures It can also be used to extract excess heat from the building and this requires the application of absorption equipment based on a continuous endothermic chemical process Building heating requires only low grade energy as required temperatures range between 5°C and 100°C

Thermal energy for buildings is a 'soft' demand Sources range from electricity supplied by utility companies, to refined fossil fuels (natural gas, light fuel oils), to heavy fuels (residual fuel oil, coal, and wood) and to solid and light wastes (garbage and sewage) Thermal energy is also available as a consequence of degradation of the energy supplied for the production of electrical and motive energy

5.5.2 Total Energy Consumption

It is difficult to state a generalized quantitative total energy consumption level for all buildings and the individual demands for the three categories of energy requirements For office buildings there are detailed records of consumption. Total annual energy consumption objectives for current-generation office buildings range between 160 kW·h and 320 kW·h per gross square metre per annum, based on 2400 h to 4800 h occupancy. The break-down of the total energy flow is approximated as follows:

Electrical	51.4 kW h/m²/a	to 60.0 kW·h/m²/a
Motive	54.5 kW·h/m²/a	to 68.5 kW h/m²/a
Thermal	32.0 kW h/m²/a	to 192 6 kW h/m²/a

This includes the energy required to operate the mechanical refrigeration equipment (12 3 to 26.8 kW·h/m²/a). The foregoing can be translated into approximate percentage figures as follows.

Electrical	18% to 40%
Motive	18% to 40%*
Thermal	20% to 60%

*Mechanical refrigeration equipment energy requirement is included

5.5.2.1 Source Energy Management Concepts

Terminal energy units express the quantity measure in the final form of consumption Source energy measurement and accounting, on the other hand, include all energy implications such as extraction, refining and delivery. To date, all energy rationalization has been in terms of terminal energy units, but it is now becoming quite evident that national interests are only served with source energy management A new set of energy values will emerge as a consequence

5.5.3 Alternative Energy Sources

The following is a brief summary of alternative energy sources for buildings. Solar and wind energy have been discussed in detail earlier in the Handbook

5.5.3.1 Solar

The contribution of energy collected with current-generation solar energy collectors (either flat plate or concentrating) is at this time quantitatively relatively insignificant but growing The current state of the solar energy art has not progressed beyond the commercial realization of low grade thermal energy (which is ideally suited for domestic hot water heating and space heating especially for the Canadian climate) Ref **Section 3.10** Technological break-throughs will undoubtedly improve the effectiveness of solar energy capture systems. At the present time the technology for electrical generation by solar energy—either by means of solar cells or turbine operation—is only at the basic research level

5.5.3.2 Geothermal Energy

Geothermal wells emitting steam and/or hot water are rare in Canada, however, the ground water temperature in populated parts of the country is relatively constant throughout the year at a temperature range between 2°C and 15°C. Within this temperature range it is therefore feasible to use the ground adjacent and/or below buildings as a thermal storage device. Required for utilization of this energy are the right combinations of thermal loads, soil and ground water conditions, property rights and the legal right to extract and to discharge water into the ground.

The ground water is suitable for use as a heat sink and the temperatures are also in a range where operation of heat pumps is effective.

5.5.3.3 Wind Energy

There are large areas of Canada where wind velocity, and frequency is sufficiently reliable to warrant the exploitation of mechanical energy by means of wind turbines Current development seems to be directed to the generation of electricity and very little is done in the line of direct wind capture for purposes of ventilation of buildings Effective uses for wind power could be found in wind turbine exhaust fans, and in wind shafts Equally effective towards conservation of energy would be the arrangement of buildings to avoid undesirable wind currents and thereby reducing thermal losses

Current codes and cost factors have hindered the utilization of wind as a direct source of energy, however, higher energy costs have kindled a renewed interest in this form of energy, Ref Section 3.12.

5.5.3.4 Agriculturally Derived Energy

Utilization of the Canadian land mass for growth of high thermal energy yielding vegetation can become a reality if the demand for energy exceeds the demand for food Some form of agricultural fossil fuels should be expected to reach the market soon, but this will not significantly alter any of the fuel utilization equipment within buildings The single most important argument supporting agri-forms of energy is that all fossil fuel at some time is derived by this method. Therefore an early start in this method of fuel production will allow for banking of new fossil fuel

For Canada, it would be prudent to re-forest as much of the unused land mass as possible, and serious consideration should be given to re-introducing grain hybrids with greater straw content The former is for assurance of long term needs and the production of straw can serve to make at least the farmer less dependent on non-renewable resources

5.5.3.5 Bio-Mass Energy

Production of fossil fuels by means of biological processes is generally defined as 'Bio-mass' based energy Under this broad definition, all renewable fossil fuel based energy can be included, however, it would be more correct to define this as a mechanism of reduction of biological matter to a readily usable fuel by means of bacterial action This method is presently used in anaerobic digestion systems of sewage treatment plants and the resulting gas is used to reduce their purchased energy requirements

Large scale plants are envisioned that produce large quantites of liquid and gaseous fuels that are of refined quality Relatively conventional equipment will be required to utilize this fuel and therefore this will not affect the design of existing and new buildings

5.5.3.6 Other Energy Sources

Recovery of energy from solid and liquid waste by means of pyrolysis and biological processes should be expected to become economical for medium sized buildings Combustion of high grade fossil fuels for the extraction of heat for buildings should give way to total energy concepts. Central utility plants based on waste recovery energy should re-emerge as commercially viable ventures There are indications that small nuclear reactors using enriched fuel

could at some time be considered on the basis of total energy utilization

Co-existence and co-operation between industries and commercial, institutional and residential buildings will play an important role in working jointly on optimum utilization of available energy and principles of conservation

5.5.4 Heating Energy Processes

Figure 5.5.4-1 shows various conventional processes as they relate to source energy concepts. Of particular interest is the natural gas fuelled internal cumbustion engine driven heat pump cycle. This process could be further improved by substituting an absorption unit heat pump in place of the mechanical heat pump and by generating electrical energy with the internal combustion engine. Resulting waste heat would be used in the absorption heat pump machine. Approximately 20% of the energy can be realized in the form of electrical power

Figure 5.5.4-2 shows some of the potential benefits of combining various cycles into a common energy management strategy.

The process combinations are applicable to both buildings and industrial processes.

5.5.5 Conclusion

The search for alternative sources of energy for buildings is essentially restricted because of our present dependence on electricity for power and lighting. This is the largest energy component required within buildings Private generation of electricity will become increasingly feasible in geographical regions where the energy strategy is fossil fuel based

Some of the potential, renewable, alternative sources of energy have been discussed above. However, while searching for new sources of energy, it should also be realized that immediate and significant results can be achieved by conservation and the employment of energy efficient systems These are the essential foundations upon which building design and operation must be based.

5.5 Consideration of Alternative Energy Sources for Buildings

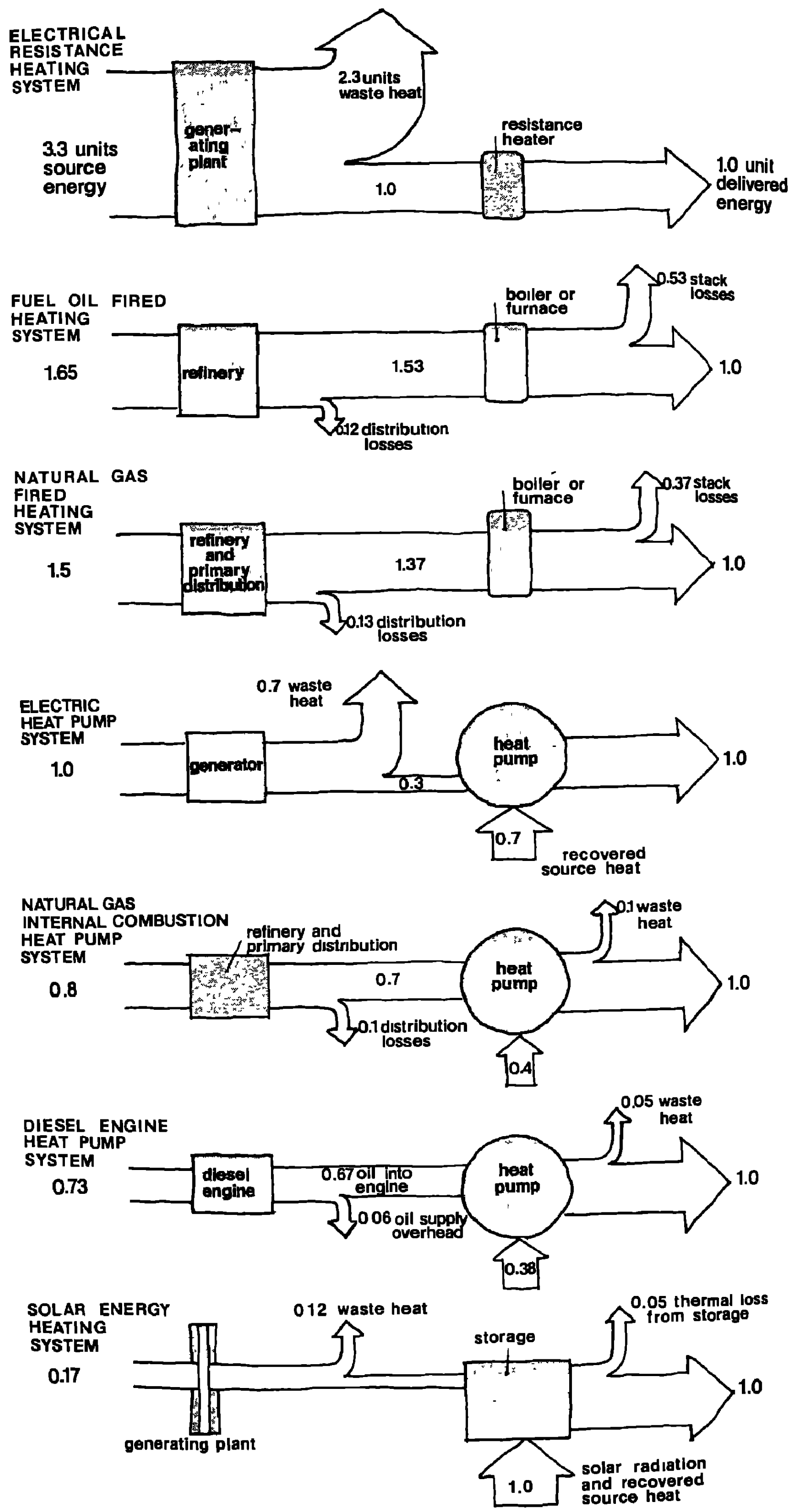
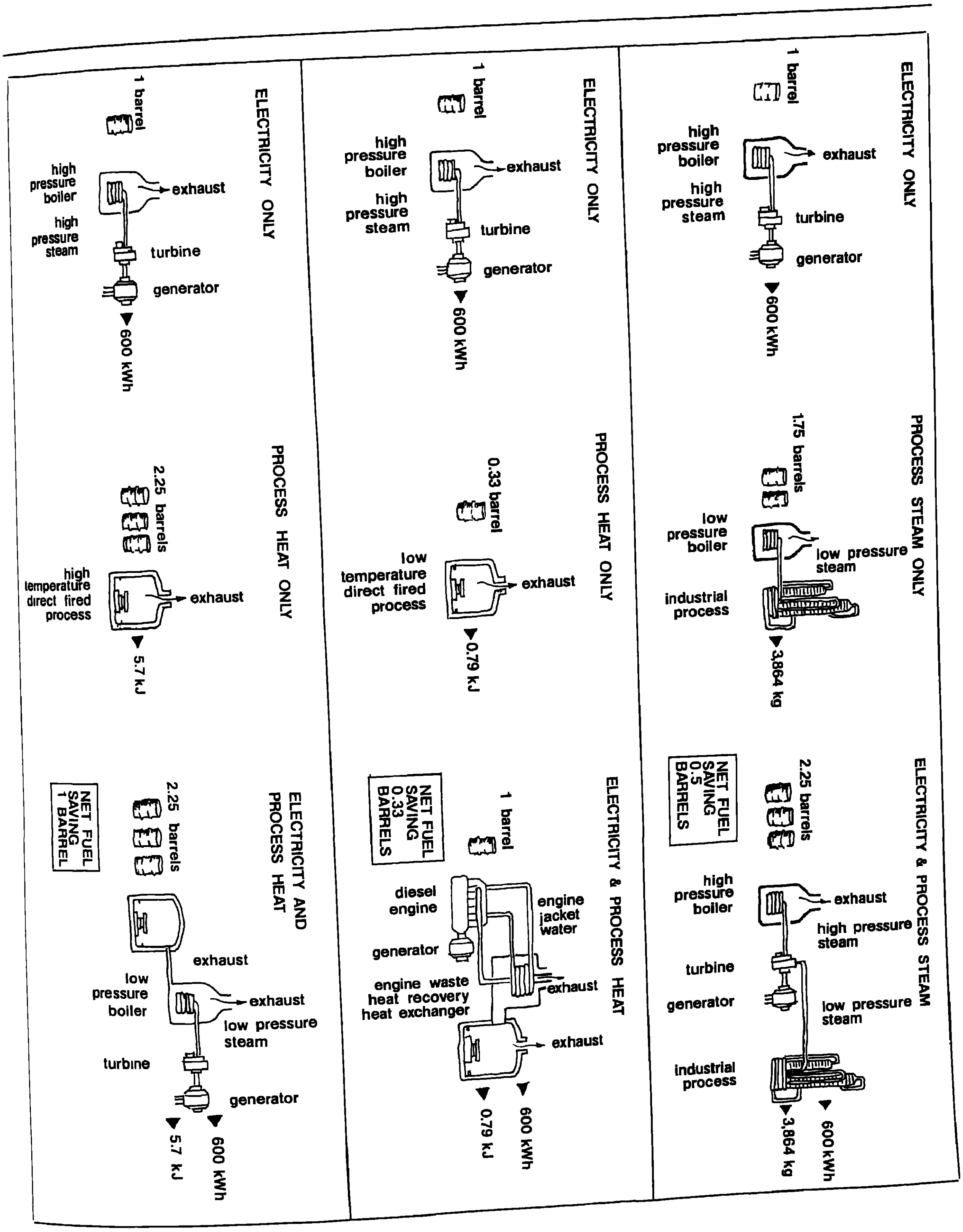


Figure 5 5.4-1
Heating energy processes



1 BARREL (AT 15°C) = 0 158 91 m³

Figure 5 5 4-2
Simple and integrated energy flow processes

6.0 Urban Planning and Development Criteria

Contents

6.1 Planning and Transportation Considerations

6.1.1 Energy Consumption

Of the total energy bill of Canada about 60% is in some way affected by the design and planning of human settlements, including their necessary servicing This figure includes 20% for residential users, 15% for commercial and 25% for transportation The industrial component, which represents almost an additional third of our total energy consumption is amenable to a small reduction, primarily in terms of building design and industrial processes but not, at least to any appreciable degree, in terms of land use planning The remaining part of our current energy consumption goes into a special form of industrial activity, which is represented by the production of useable energy

We will be returning to that last increment of energy consumption, which represents a rapidly expanding proportion of our national energy bill First of all, it will be useful to consider some figures that give an indication of the order of magnitude of energy savings that could arise from better land use and planning in general, as distinct from better application of purely architectural principles, which occupies most of the body of this Handbook To do that we must place our current urbanization in its historic context, most importantly in order to see what constraints (and opportunities) past forms of urbanization may have created and how they influence the ways we now spend energy in our expanding urban environment

6.1.1.1 Historic Context

.1 The Pedestrian Era· This characterized urbanization up to the Industrial Revolution in the West, and essentially still does in many parts of the world Its distinguishing features are high densities and no separation between land uses of the kind introduced by modern planning Also, some of the settlements were quite large—ancient Rome had a population of well over a million. Expenditure in non-renewable energy was nil

.2 The Transit Era: With the Transit Era came a surge in the consumption of non-renewable resources, primarily in the form of coal which was used to fuel industry, to heat houses and tenements and to power the transit system Generally, this was a streetcar system that took workers to their workplaces—usually over fairly short distances by today's commuting standards, as almost all of them were located in and around the centre of town The transit system was also the shopping conveyance and shopping was more or less continuous along its path with concentrations at transit stops and intersections of routes The result, shown in Figure 6.1.1.1-1, was a system of major transit routes, radiating out from the centre, with most housing located on lateral roads leading off them

.3 The Automobile Era: Now that we are in the Automobile Era the merits of the Land Use—Transportation arrangements of the Transit Era are beginning to be appreciated, at least from the point of view of energy conservation. The irony is that we have spent and are still spending large amounts of money trying to break out of the constraints of existing Transit Era land use and transportation infrastructure.

Probably the prime manifestation of this effort is the suburban house (and neighbourhood). Its extreme condition, truly the epitome of the mobility that the car gives, is sprawl. Sprawl, essentially a parasite on the inter-urban road system, provides what at first looks like cheap land to the buyer by removing him/her from many of the

6.1 Planning and Transportation Considerations

servicing expenses of land closer to the centre and by tapping a transportation artery paid for by the public at large The costs it adds to our collective energy bill, as well as to the energy bill of the sprawl resident himself quickly negate that advantage

Commercial development has also been affected in the Automobile Era What used to be, in the Transit Era, a well-apportioned commercial frontage on the major transit arteries, with emphasis on transit nodes, became linear commercial sprawl—completely oriented to the passing car Nodal commercial developments do occur, but for access their developers wisely avoid those arteries which are already heavily fronted with commercial development and typically, too congested to carry prospective customers conveniently to the shopping centres Until recently at least, as the automobile driver has been curiously oblivious of the actual cost of the trip, it has benefited the developer to locate his shopping centre at major highway crossroads or freeway intersection regardless of how remote the location may have been from the centre of the city The more isolated the location, the more unencumbered by other land uses, in short, the more it contributed to sprawl, the more likely it was to be chosen by the motorist over other competing shopping centres

The result is more and more remote and extensive commercial developments Also more remote and extensive workplaces, industry also falls in step with sprawl with the construction of large industrial parks, in every way resembling the shopping centres And the trend extends to office buildings as well, a surprising development, given that white-collar workplaces offer neither the land use conflicts of industry nor, obviously, do they involve the same elements of choice of location that commercial developments do

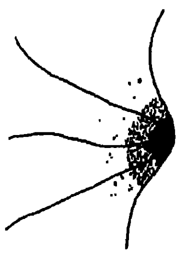
Most of the energy-consuming attributes of the Automobile Era discussed so far have centred around transportation, now a user of energy in about equal proportions to those of the residential and commercial sectors (if commercial transportation is excluded from transportation energy usage)

This massive expenditure of energy to transport people is, theoretically, one that can be reduced drastically, either by crisis-generated expedients, such as the closing of gas pumps on Sunday or by the far more rational policy of promoting mass transit By comparison, energy reductions in the static land use aspects of the residential and commercial sectors have their limitations, especially where existing buildings are concerned

If all workplaces had remained in the urban centre, the switch from car to transit would be simple. it would just be a matter of going back to the Transit Era, with the addition of some car travel from the outer sprawl areas to and from the termini of transit lines The problem is that since the end of World War II much of our highway building effort has been towards ring roads rather than radial ones, **Figure 6.1.1.1-1**. After many unsuccessful years at trying to keep down peak traffic volumes (the dominant variable in highway capacity design) by building more radial highways, planners gave up and started encouraging the dispersal of all land uses to the suburbs Multi-destination commuting produces lower volumes on any given highway than commuting to a single centre. As a result most North American cities now experience more tangential than radial commuting. While this may have saved some downtowns from being totally obliterated by roads it has also made a return to the Transit

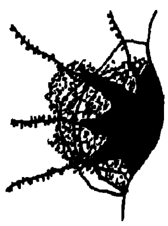
Era very difficult a diffuse, tangential Transit System is expensive to operate (and to fuel). Only a return to inner city living and/or policy of attaching new land uses to specific new transit corridors can remedy the situation.

In the following pages, reform of our transportation habits directed towards greater energy parsimony will be discussed only where they have a counterpart in architecture and land use.



A. pedestrian era

B. transit era



C. automobile era

Figure 6.1.1.1-1
Three eras of urbanization and transportation.

6.1.1.2 Opportunities for Architects

.1 The advantage of size, Figure 6.1.1.2-1: The importance of the relationship between building volume and outside skin area in terms of heat loss has already been discussed in Section 4.4. Research has shown, for example, the greater efficiency of multi-story, connected dwellings compared with the individual, single family home.[1]

This efficiency is heightened by the fact that apartments housing a certain household are smaller than the single family home that the same household would typically occupy. Accordingly, savings in energy have been estimated as high as 60% per unit for space heating.

Architects could commence by examining low-rise, high density designs. A large number of successful, economical, marketable and highly imaginative solutions have been produced over the past few years. For example, a density of 300 persons per hectare, once thought to be a high rise density, is easily achievable at under six storeys and may even lend itself to walk-up solutions.

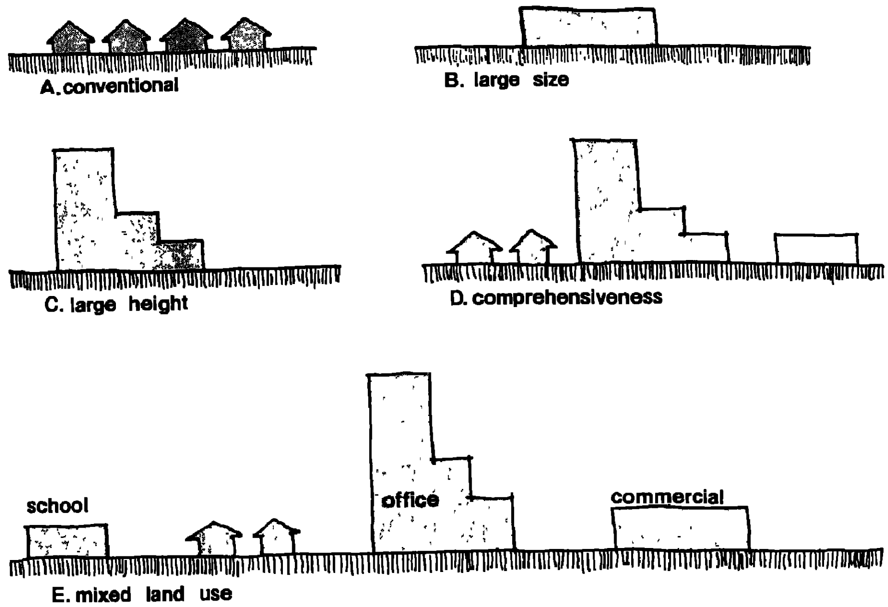


Figure 6 1 1.2-1
Building configurations, land use

.2 The advantages of comprehensiveness, Figure 6.1.1.2-1. There is a form of basically residential land use that combines considerations of size and height with other factors which all together have definite energy consumption implications, the Planned Unit Development (PUD)

The PUD, as defined by others[2], is a housing project with the following characteristics

—dwelling units grouped into clusters, allowing an appreciable amount of land for open space
—much or all of its housing in townhouses or apartments, or both
—higher densities than conventional single-family projects of the same land area
—often, part of the land used for nonresidential purposes, such as shopping and employment centres

Compared to sprawl, the Planned Unit Development is said[3] to be up to 45% more economical in energy use when a design capitalizes on all its inherent advantages These include the lower servicing costs, achieved through clustering, the higher overall densities, the presence of larger, more specialized and more 'tightly' designed open space that cuts down on recreational driving outside the PUD and the enhancement of public transit usage and facilities arising from increase in ridership.

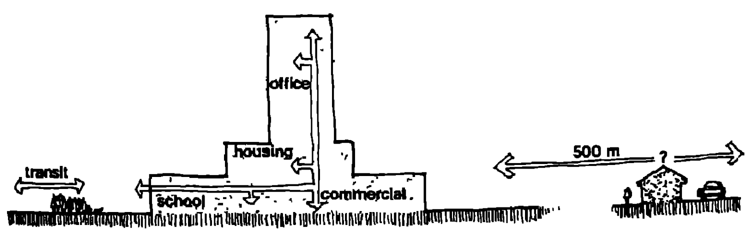


Figure 6.1.1.2-2
Land use, compactness vs. sprawl

.3 **The advantage of mixed land use, Figure 6.1.1.2-1**: The energy advantages to be derived from non-residential admixtures into the Planned Unit Development were deliberately left out of the discussion up to this point This is because they are much less predictable than the other benefits which a well designed comprehensive land use configuration is more or less guaranteed to produce.

Consider the admixture of workplaces into the PUD Commuting to work by car uses by far the largest amount of people-transportation energy. So why not provide the workplace inside the PUD? The answer is simple. labour mobility is at the core of a liberal democratic society In planning terms it is probably the single most important factor in the growth of our large metropolitan areas over the past hundred years

So it is not surprising that under the best of circumstances only about 15% of the people living in a comprehensive development such as the PUD can be expected to work there as well[4]. 'The best of circumstances' usually means a large land use conglomerate —closer to the New Town than to the Planned Unit Development— such as seldom gets designed by even large architectural offices

Yet the admixture of land uses presents tremendous energy savings opportunities Happily for the audience to which this Handbook is directed these savings may be more a function of building design, or rather, building program design, than of raw land use admixtures, although there would also seem to be obvious transport implications

Leaving workplaces aside for the moment, the way to minimize energy usage (and, incidentally, to maximize profits for the development) is to bring together interdependent land uses Residing somewhere and shopping elsewhere for staples is the prime example The two key variables that the architect must be aware of in trying to combine the land uses (or rather activities) involved in that example are

—size of the complex· the larger commercial unit being more competitive with other shopping centres and more capable of attracting outside shoppers; the residential component of the development having to follow suit in its size if there is to be significant travel abatement as a result of the admixture.

—compactness of the complex the issue being from the energy conservation point of view, to dissuade the resident of a mixed use complex from jumping into the car and driving to do the shopping.

What is the acceptable minimum that people are willing to walk to do their shopping, assuming a well stocked and diversified shopping facility in the first place? A figure of up to 500 m has been suggested as being competitive with the annoyance of walking to one's car, warming it up, getting out of the parking space, etc, but this distance is obviously out of line with the 50 m to 100 m walk usually given as tolerable as a matter of daily course between one's housing unit and one's parking spot.

This uncertainty may account for the popularity of a relatively new form of residential-commercial mixed use complex, where everything is combined under one roof **Figure 6.1.1.2-2.** The advantages from the point of view of energy are overwhelming, compactness and concomitant discouragement of car travel are maximized, heat losses can be minimized and the possibility of shifting recovered energy from one part of the building to another or from one time of the day

to another is always present As we will see when total energy systems and district heating are discussed, the possibility of having an even demand for electric or space heating energy, combined with low transmission losses is very strong in a complex where land use mix has been as carefully considered by the energy-conscious architect as building massing, envelope and orientation

Well designed admixtures of land use can offer car travel abatement of 20% to 30%[5], a sizeable gain translated into energy saved This saving is probably even higher if the complex is located on a major transit route. The new factor here is the possibility of mixing in uses that bear little or no intrinsic relationship to the main land uses in the mixed use complex This includes the possibility of public or subsidized facilities, such as schools, day care centres, etc oriented to the passing transit user in addition to the local resident This transportation-based concept could be termed Second Generation Mixed Land Use to distinguish it from First Generation Mixed Land Use where inter-relatedness of component land uses reflects primary concern with car travel abatement

.4 **Summary:** In this overview of what the architect should consider regarding land use and transportation we have, in a sense, come full circle The transportation factor has been identified as the most intractable where energy conservation is concerned and at the same time the transit route has been suggested as the setting along which the biggest energy conservation payoffs may be possible at the planning scale The energy-conscious architect would be well advised to become familiar with the effect of nearby transportation routes and modes on a client's site when proposing land uses for it At stake may not only be energy savings to the client and to society in general but also some good conventional profits to the client from a project whose whole may be greater than the sum of the parts

6.2 Site Analysis and Selection—Off Site Factors

6.2.1 Latitude and Climate

The following should be read in conjunction with Section 2.1 External Spaces and Climate

6.2.1.1 Climatic Zones

For the purposes of this discussion the major climatic zones are defined as follows (the vast Arctic region has been excluded as it presents energy related problems of an entirely different order of magnitude)

—The temperate region, west of the Rockies and in the southern part of Ontario and the Maritimes, characterized in the winter by a 40% probability of sunlight, a predominance of north west winds and approximately twice the insolation on south facing as on east or west facing walls; in the summer by a predominance of south-westerly and south-easterly winds on the west and east coasts, respectively

—The cool region (excluding Arctic Canada) with somewhat lower winter sunlight probability compared with the Temperate Region, somewhat higher summer sunlight probability and prevailing winds in winter and summer in the northwesterly and south-easterly, respectively, directions.

6.2.1.2 Opportunities for Architects

In both the above zones it becomes important to design for as much solar radiation and heat absorption through passive means as possible in the winter and as little northwestern exposure as possible In the case of the cool zone, however, the first objective, that of letting in the winter sun through the southern exposure of the building may have to be tempered by the overriding objective of cutting down on all heat loss through radiation to the outside Conversely, while the maintenance of a proper environmental response is three times as important[1] in the winter as in the summer for that zone, in the temperate zone conditions are more balanced between the seasons and allowing breezes to come in in the summer is an important design consideration.

6.2.2 Configuration

The ideal configuration for a building which is more heavily glazed (exposed) in its front than in its back, for both climatic zones which were discussed, is location on the south facing slope of a hill, not too close to its crest (to avoid winds) and not too close to the valley (to avoid cold night air and mist) A steeper slope may additionally allow for the burial of the north (back) side of the building for better insulation, while perhaps also increasing solar penetration on the south (front) side.

Naturally, this ideal configuration is seldom obtainable. Also, more climatically refined specifications would distinguish between zones as described below.

6.2.2.1 Temperate Zone

For this zone, the requirement that the slope and building face directly south can be relaxed since penetration by summer breezes (which, as mentioned, range from the southeasterly to the south-westerly direction) is as important as maximum isolation in the

winter Given a choice of southeast to southwest exposure, however the former should be preferred, not only to avoid heat buildups from exposure to the western sun in the summer but also because a building facing southeast presents its back to the predominating northwestern winter winds

Water bodies of some size are positive factors in this zone because they contribute cool summer breezes, exceptions can be found on the ocean where coastal fogs should be avoided at all costs

6.2.2.2 Cool Zone

For this zone, protection from winter winds is paramount This means building on the lee side of whatever hill will block the wind Since prevailing winter winds are northwesterlies this will usually mean some southern exposure for the building, which is very important for whatever solar heat it is able to absorb passively

Water bodies may have to be avoided since they help build up wind speeds, unless there is an adequate on-site vegetation buffer The role of vegetation is examined elsewhere in the Handbook, Sections 2.1 and 6.7.

6.2.3 Off Site Services

Reference has already been made to the relationship between land use and transportation on the one hand and energy consumption on the other. Also discussed was the relative advantage, albeit minimal from the point of view of energy consumption, of urbanizing next to areas already adequately serviced, compared with the creation of amorphous sprawl with its dependence on the land for water and sewage treatment The argument has been that the extension of existing services was cheaper than reaching out with an extensive network of sewers which sooner or later would become necessary under sprawl conditions. It was an argument that came in handy when planners sought in the past to restrict sprawl for a variety of reasons, probably including a vague uneasiness about its inherent energy costs, now looming so large

Ironically, the idea that central services were good for the public purse, that they were the hallmark of good planning and that they were the prime determinants of orderly urbanization is now beginning to come under attack, at least partly for reasons related to energy, the cost in energy of sewage treatment is high, the cost of it in construction, maintenance and operating money is also high as is the cost of the piping and the other hardware that conveys sewage to the central treatment plants

6.2.3.1 Historical Review

The most common alternative to central treatment, the septic tank/dispersal field system has always been disreputable, principally because of problems associated with improper leaching of effluent If land unsuitable for building had been identified ahead of time, such problems could have been avoided However, under most regulations, still in force, the developers were economically pressed to use as much of a land parcel as they could.

Residential land subdivision in Canada has moved very little in terms of design from the original New World gridiron pattern

Streets have been curved to cut down on a monotony and to facilitate gravity flow of sewage but the result has still been total coverage of the site, with the exception of public roads and often perfunctory parks In fact, the advocate for energy conservation under present suburban design rules would have to say that the old gridiron was a superior form of lotting when properly oriented with its long streets oriented in the east-west direction At least all houses had their fronts or backs facing south, allowing for passive solar heating of their interiors on one of the two usually most fenestrated sides

The capriciously curvilinear layout of the 'modern' subdivision did not provide this benefit for many houses which were located without regard for orientation. This was not, in any case, what the Garden City movement had intended when it launched the suburb half a century ago.

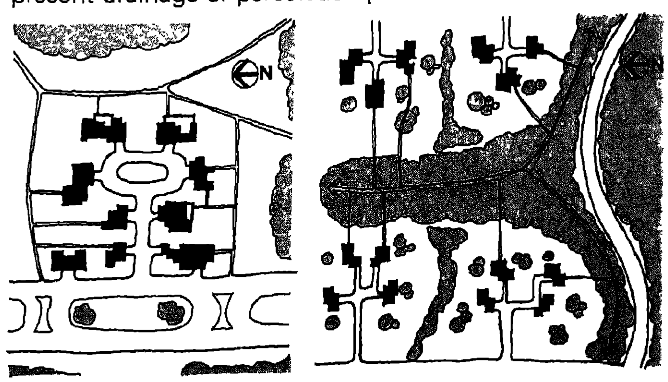
What it had intended is heavy use of cluster design and this will be discussed in further detail.

6.2.3.2 Cluster Design

Cluster design involves trading off a reduced lot size for a larger amount of better designed public or semi-public open space. In the Radburn, New Jersey, prototype, (still a classic illustration) and in a contemporary example, **Figure 6.2.3.2-1**, one can see the intent behind the design—the small cluster of housing units with a fringe of public land, that is really only semi-public, on the back yard side, and then a further assembly of a series of these clusters around a larger, truly public, green area. The reason why the cluster did not find very wide acceptance in Canada was the reluctance of municipalities to take on the ownership of an extensive network of open space with the obligation to maintain, police and service it. The Planned Unit Development presents a different situation. The owners of the development are responsible for the public portions of the PUD and cluster design has become administratively easier to implement. As the definition of PUD stated, it has, in fact, become integral to the entire concept

Considering on-site services, cluster design offers the following possibilities:

—the development of a site plan to avoid use of land that will present drainage or percolation problems



A. HOUSING UNITS B. SUBDIVISION

Figure 6.2.3.2-1
Cluster design.

—the setting aside of large parcels for the leaching needs of collective septic or other localized sewage disposal systems
—the installation of small-scale waste water treatment units, energy efficient and relatively inexpensive in terms of both capital investment and operating cost

A double-edged sword has been presented here While it is true that such decentralization of services in conjunction with cluster design may lead to savings in energy and money, it is also true that its wholesale adoption may remove the most effective anti-sprawl argument that planners now have This issue will be discussed later on Suffice it to say now that cluster design, by working with a building quantum that spans the scale between the single building on the one hand and the undifferentiated continuous development on the other, facilitates consideration of the scale appropriate to each servicing system Also, in many ways, it is a vehicle for raising the consciousness of the designer to the varying degree of appropriateness of many of the constituents that make for successful land use, whether or not these are energy-related The next section of this review will become more specific about the 'tuning' of the energy conversion technology to the size of the cluster, or land use quantum that works best with it Some obvious devices can be specified in the present context which are often much within the purview of the architect They are as follows

.1 **Micro Scale**: At the micro scale, clustering makes possible the use of zero-lot line and shared party wall design discussed elsewhere in the Handbook It should not be overlooked here that it is the land use arrangement (usually, in the form of PUD) that makes possible the application of an obvious architectural energy-saving device Many architects are unaware of this larger picture and often deplore the stupidity or inertia that prevents useful features in building design from being implemented, without considering whether or not these fly in the face of a larger, community-wide perception of how things should be done

.2 **Orientation**: Proper orientation of a block to take advantage of active or passive solar energy is much easier when that block is a cluster surrounded by green space than if it forms part of a tightfit subdivision

.3 **Relief from Uniformity**: Cluster design cuts down on the perception of uniformity that would occur in a conventional subdivision which is, for example, oriented optimally towards the sun each cluster can be visually isolated from the other ones

.4 **Application of Energy Conversion Systems**: Cluster design takes into account the fact that some of the energy conversion systems whether or not based on renwable sources of energy, which were developed in the wake of the first awareness of the energy crisis have turned out to be applicable at scales other than the single house or commercial building

6.2.3.3 Anticipated Developments

The main issue that will determine the acceptance or otherwise of non-central forms of servicing, beginning with wastewater treatment is the existence of appropriate administrative arrangements and bodies. These will be required for the monitoring of on-site systems of any kind set up to service clustered buildings or, generally, land uses belonging to more than one owner The reason is that singly

owned systems (whether septic tanks or package plants owned by an enterprise or development) are the responsibility of one owner or condominium of owners, easily identifiable by the law. In contrast, the on-site system that meets the new servicing and energy saving concepts advanced here will not necessarily be so; it may be a treatment facility shared by a group of people who own nothing else in common and who may well disclaim responsibility for the maintenance of the facility.

This would make municipalities reluctant to go along with the concept of the on-site mini-utility if certain new trends in funding by senior levels of government were not also occurring.

.1 **Changes in Funding**: The Canadian government, as evidenced by the recent (early 1979) amendments to the National Housing Act, will be moving towards block grants to municipalities permitting much discrection in their allocation and spending, in preference to the old pattern of mounting programmes to meet specific municipal needs and deficiencies as perceived at the senior levels of government, e.g construction of central sewage treatment plants

Parts of the NHA have been replaced by an umbrella programme that should interest the architect in that it is a harbinger of similar composite programmes increasingly, one predicts, to be concerned with energy It combines such formerly disparate activities as water treatment, neighbourhood improvement activities and community buildings To the alert architect the message should be clear He/she should be gearing up to anticipate and direct the needs of a municipality which has received such a loosely tied grant towards a package of public investments that includes a fair share of built space This is a different sort of operation from making sure that one's firm will get the contract for a new school It involves an understanding of municipal finances, especially of its energy budget, for both public and, insofar as public infrastructure is involved, private community-wide facilities

.2 **Architects Role**: Architects will, if prepared to upgrade their consulting capability, be instrumental, in having the concept of the Public Utility District[2] accepted in a municipality which, frequently, is not completely covered by a central wastewater treatment system

In rural municipalities this may, for example, be a matter of demonstrating how future housing may be distirbuted in clusters on land unsuitable for farming but having enough overall absorptive capacity for a series of on-site systems. Such an approach, would be of greater benefit, and would involve less cost to build and operate, than if a strip of prime agricultural land were to be opened up for subdivision with the building of an expensive new sewer extension —the usual solution of the past

6.3 Concentration of Energy Sources and Energy Conversion Plants

6.3.1 Function and Management

There is a direct analogy between the concept of the Public Utility District as the agency responsible for the treatment and disposal of wastewaters and other urban wastes and its role as the agency responsible for an equally decentralized energy conversion and supply function In fact, as we are about to see, the two may be linked in technical as well as administrative terms

The search for alternate sources of energy, those lessening our dependence on non-renewable resources, has largely been a history of search by individuals or small communal groups for closely integrated ways of turning resources at hand to energy advantage While exciting in their inventiveness, they have usually taken place in special rural land use units having access to far more in the way of natural resources than is available to the average Canadian urbanite If we add to this that Canadian climatic conditions are unsympathetic to some of the methods involved, we arrive at the need to tie the scale of the energy converter to a size and composition of land use agglomeration that combines economies of scale, and troublefree management, with the overall objective of energy parsimony

The use of the term 'economies of scale' is ironic in that in the past it has led to ever larger energy production units, just as it has in the field of wastewater treatment In both cases this practice has come under question, at least partly on an energy-efficiency basis

At the other end of the spectrum, 'economies of scale' involves the pooling of highly individualized energy production units as well In some cases, this will be dictated by technical factors In other cases it will be the land-use and the architecture that suggest the technics of the energy supply unit

6.3.1.1 Opportunities for Architects

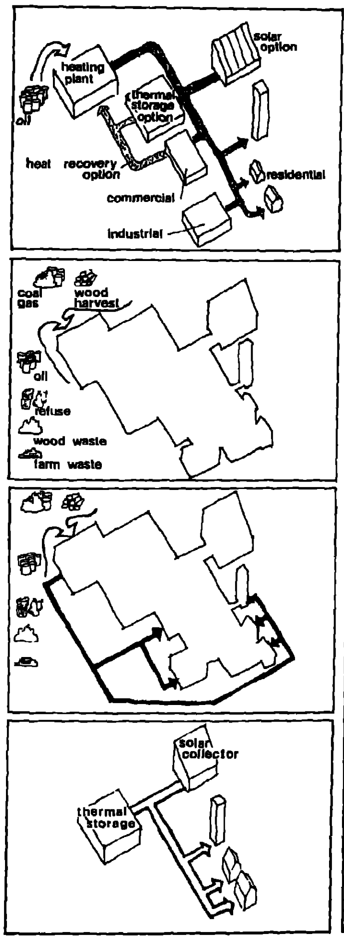
Letting the energy conversion system be determined, or at least influenced, by the size and built form of the land use quantum dependent on it places some serious demands on the design acumen of the architect Consolation may be found in the fact that, as has already been pointed out in this text, the architect will at least have a role in the process, a role not available in most of today's single family housing and most single or small communal projects in which alternate energy technologies have been spawned or tried out Let us review some of these systems and identify the architectural issues that come with them

.1 **Solar:** Many active solar space heating systems tried out in Canada on a single-family house basis have fallen short of expected energy output The problem has been the high cost of the large storage facility necessary under Canadian conditions Geometrically speaking a larger storage facility serving more than one housing unit is more economical, as tentative studies conducted by the Central Mortgage and Housing Corporation have indicated [(1)] Swedish studies[(2)] for climatic conditions similar to Canadian ones have suggested that a system serving a clustering of about 30 units would be optimal. **Figure 6.3.1.1-1.**

The architect has an unique opportunity at the single building scale in the implementation of passive solar systems and the reader is referred to **Section 3.10.**

.2 **District Heating:** Central supplies of steam for industrial operation or space heating are not something new to hospitals and other

6.3 Concentration of Energy Sources and Energy Conversion Plants



ENERGY CONVERSION SYSTEMS	No OF UNITS IN FEASIBLE DEVELOPMENT	
District Heating Conventional Fuels	Canadian norms	600 to 2200
	Sweden	500
	Fast track PUD	100
District Heating Unconventional Fuel Combinations	Canadian prototype	2200
	Lower limit (unresearched)	?
Co-Generation or Total Energy System	U S prototype	500
	Lower limit (unresearched)	?
Active Solar		20 - 30

Figure 6 3 1 1-1
Type and optimal scale of energy conversion systems

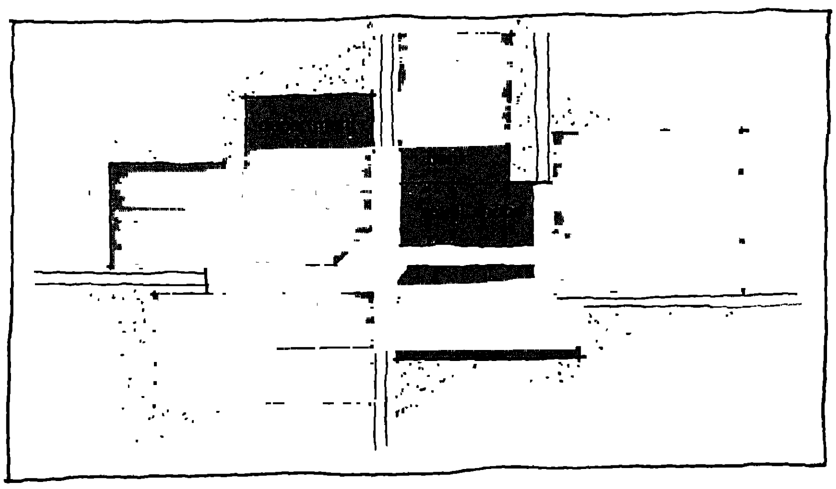


Figure 6.3.1.1-2
Leaf Rapids, Manitoba, new town centre.

6.3 Concentration of Energy Sources and Energy Conversion Plants

institutional complexes The extension of the principle to a collection of separate buildings and land uses is called district heating and has already been discussed in detail in **Section 3.11**.

Mixed use compact buildings of the type designed, say, for the new Town of Leaf Rapids in Northern Manitoba offer the opportunity for heat recovery from internal generation in conjunction with district heating (this particular building is, however, conventionally heated) The Leaf Rapids Centre, **Figure 6.3.1.1-2**, serving a population of 2700 people, is surprisingly large, about 20 000 m^2, because it contains just about every non-residential function in this mining town

The minimum feasible scale for district heating might well be a relatively small community, perhaps of PUD size, in which there is a similar combination of building mix and high overall densities which cuts down on heat transmission distances and overall heat requirements The introduction of a residential component would help to even out the daily, 24 h, demand.

6.3.1.2 Anticipated Developments

The most dramatic change in the distribution of our energy consumption forecast for the end of this century is in the energy supply industries. A tenfold increase is projected primarily attributable to a rapidly expanding electricity generating industry

Unless things change drastically, this industry will be a monumental waster of energy. As discussed elsewhere in the Handbook, electric generation is now only about 33% efficient with the remainder of the energy that goes into the process (mainly non-renewable) being dissipated in lost heat around the plant or through transmission losses An idea of the magnitude of the loss can be given by the fact that this waste of energy in the year 2000 would equal that expended in 1970 by the residential, commercial and transportation sectors put together

Most of this energy that is wasted can be recaptured, as discussed elsewhere in the Handbook. This involves a special type of district heating, Co-Generation, **Figure 6.3.1 1-1**. The result is often referred to as a Total Energy System, when waste energy has not only been made available but has also been wisely used. It is this last aspect that should involve the architect of the future Looking at it from that point of view, we have an interesting statistic Approximate comparisons of primary energy input to energy available at point of use show an all-electric building is 33% efficient, a conventionally 'energized' building is 50% efficient, a district-heated one is 58% efficient while one which is part of a total energy system is 85% efficient

Under today's electricity generation patterns, the architect's involvement in co-generation would not seem to be intimate Transmissions of hot water for distances upwards of 50 km have been carried out[3] without appreciable heat losses on the way, so the land use need not be a functional or formal part of the generating industry In other words, an existing conventional plant could be retrofitted to become a source of district heating for land uses far-away.

But there may be additional advantages in small-scale co-generation from the point of view of evening out the local 'peaks' and 'troughs'

in electric demand. The previous section indicated how certain land uses go hand-in-hand to produce an even demand for heat in a district heating system In some cases that system may in turn go hand-in-hand with co-generation to produce an even daily demand for heat and electricity in terms of energy input (usually not in the summer, however)

Architects will be drawn into the implications of co-generation not by the system itself, but by the new urban and land use arrangements likely to emerge Besides the small scale just discussed, these are also likely to take the form of new towns or settlements when existing generating facilities are retrofitted The added fact that co-generation also takes care of thermal pollution problems may dictate its first large scale introduction through such retrofits

The location, land use composition, and the architecture of all these new buildings or settlements will ultimately, however, be related to emerging demographic changes which will be examined in **Section 6.4**. These have already begun altering our urban and rural development practices—and are likely to do so even more in the foreseeable future

6.4 Population Growth

6.4.1 Implications for Canada

In Canada, we are moving towards an older, on the average, population Except for a small youthful surge around 1990 when the grandchildren of the famous war babies will be coming to this world (in numbers very much dependent on the procreative enthusiasm of prospective parents) we will experience collective aging The consequences of this phenomenon, providing there are no drastic changes in immigration policy, will be as follows

6.4.1.1 Future Changes

.1 **Changes in household composition**: These will naturally follow from the relative (and absolute) increase in the numbers of the aged and the relative (and perhaps also absolute) drop in the numbers of nuclear families, which have fuelled the suburban movement since the 1949 National Housing Act was passed They will also follow from another source, over the past few years there has been a sizeable increase in the number of households which would be called unconventional in 1949. They are single parent households, joint single parent households where two of more single parent families cohabit under more or less communal circumstances, other childless versions of these joint households involving people of the same or different sex, singles who might in the past have lived in rooming or boarding houses or with parents, and so forth The net result will be a possible increase in the number of households, even as overall population declines and the relative share of the residential sector in energy consumption drops

.2 **Changes in employment**: A continuing trend away from secondary (industrial) and towards so-called tertiary occupations (mainly white-collar) will lead to an increase in office space

.3 **Changes in regional urbanization**: Recent Canadian censuses have shown a decline in the rate of growth of large metropolitan areas and a rise in the rate of growth of urban areas in the 20,000 to 50 000 population range Whether this reflects a greater decentralization of economic activity or simply reluctance to emigrate to large metropolitan centres is open to speculation, but in terms of energy use it has some very definite implications There are indications that commuting is twice as extensive in cities of over one million population as it is in ones of under 100 000 [1] Before becoming too enthusiastic about this development, however, we should keep in mind that it is far easier to establish a high modal split (high transit usage) in large than in small urban centres

6.4.1.2 Anticipated Architectural Developments

Many of the developments described below have in fact, already begun

.1 **Mini-utility systems**: The changes in age composition are beginning to affect the share of subsidized or public housing that goes to the aged.

The scale of the groupings of units and fact that they may frequently be located in a land-extensive setting should be of interest to architects because they lend themselves to the incorporation of mini-utility-based systems. These could include (a) grouped solar systems; (b) small burner units that provide heat and/or domestic hot water fuelled by locally available agricultural or forestry byproducts and solid wastes collected from near-by communities; (c)

methane digestors; (d) all of the above perhaps in conjunction with waste-water management systems Figure 6.3.1.1-1.

The technology for complex multi-purpose mini-utility systems is rapidly being developed (refer for example to CMHC's CANWEL system), but, as already mentioned, the administrative component is not Architects are in a strategic position for 'making it come together' by incorporating appropriate utilities into small building complexes which, to begin with, are under a single administrative authority In some localities, these may in fact, become 'seed' authorities for the creation of community-wide public utility districts.

.2 **Adaptive re-use of buildings:** Changes in household composition in a sense, parallel what is happening to another segment of the aged population that was not touched on above, namely the aged urbanite In both cases we will be dealing with demand for new units by households which lack the two essential ingredients of suburban existence children and cars. This will have important architectural implications due to the increase in adaptive reuse of existing, mostly inner city or inner town, buildings for an expanded number of housing units, with all the concomitant energy conservation possibilities that retrofit involves

In terms of energy, the major benefit of adaptive reuse is, of course in the boost to public transit that comes from accommodating the carless in an urban environment where most support land uses are within easy reach Where new construction is concerned, the fit between housing for these households and transit can be a matter for architecture rather than fortuitous land use One can only reiterate here the importance of exploiting transit stops as sites for mixed use buildings or complexes for the variety of needs that the 'new' households will have Again, it is important to make the distinction between First Generation Mixed Land Use and this Second Generation of Mixed Use buildings or complexes where the mix in a sense takes place over the entire transit line or system

.3 **All-purpose buildings:** Changes in employment will tend to reinforce the implications of adaptive reuse and of transit-based mixed land use. Small offices and white-collar workplaces can result from the break-up of large older buildings or the infilling of a vacant site to accommodate more households or activities in the central city

The similarity in scale between these and other varied land uses and the fact that, in the case of adaptive reuse, they may all be accommodated in the same basic building types has given rise in Europe to the pursuit of an all-purpose architecture of buildings in which different land uses and households can actually succeed each other over time. These 'loose-fit' buildings, designed from the onset to facilitate future adaptations, are in a sense the ultimate in energy conservation: they address themselves not only to the issue of transportation economies, but also to the advantage, in energy conserved, of easy retrofit and adaptation to the demographic uncertainties of the future.

6.5 Spatial Relationships of Buildings

6.5.1 Buildings and Climate

Buildings, as much as natural vegetation or earth forms, can influence climatic effects

6.5.1.1 Effect on Wind

Unlike rows of trees and bushes which are porous enough to induce a jet effect through their structure, with beneficial overall results buildings are hard edged and hard surfaced and sometimes produce undersirable eddy effects, while effectively moderating broader wind conditions elsewhere Thus it is possible to state that a vegetative barrier of a certain height set perpendicular to the predominant wind direction will more or less always work However, in order to judge the efficacy of a row of buildings as a wind barrier, one would have to know more about the length, width, height and angle to the wind

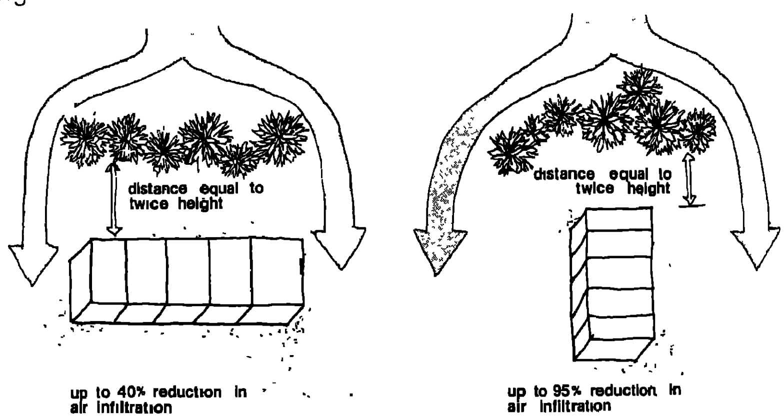


Figure 6 5 1 1-1
Air infiltration in shielded rows

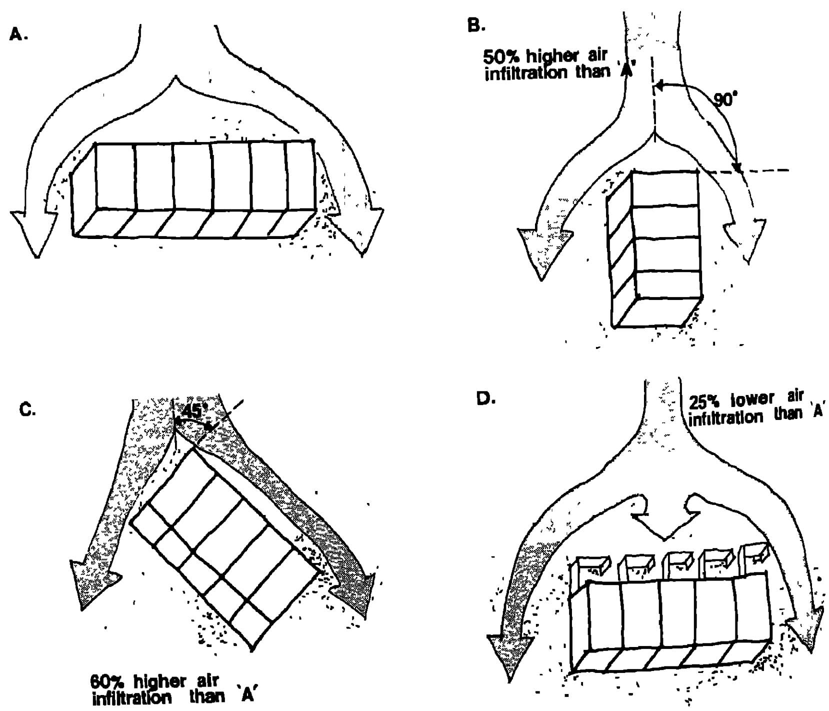


Figure 6 5.1 1-2
Air infiltration in non-shielded rows.

The difference is analogous to the great variety of wind speeds and thermal gradients obtained when one experiments with fences which are solid or louvered in various configurations

As a rule, to be effective as wind breaks, rows of buildings should be oriented perpendicular to the direction of the winds to be deflected as in the case of a vegetative barrier, unless, as **Figure 6.5.1.1-1** shows, that row has already been protected by a wind barrier or lies in the interior of a complex of buildings In that case, a row orientation parallel to the new reduced wind is preferable The worst result is obtained when the row, or to generalize the example, when a building mass rectangular in plan, is oriented at 45° to the direction of the wind air infiltration in that case can be up to 60% higher than if the long axis of the row or building faces the wind head on, **Figure 6.5.1.1-2.**

.1 **Wind Speed:** It was stated earlier that wind speeds of up to 20% higher had been recorded at the top of ridges compared to those at their bottom. Free standing tall buildings are subject to similar wind acceleration, a fact that can put into question the efficacy of taller buildings when it comes to considerations of heat loss through the thermal barrier of the skin In addition, the effects of these accelerated air streams on passers-by must also be taken into account

.2 **Meso Scale·** So far, discussion has been addressed at the scale of the cluster While the cluster has often been referred to as the fundamental building block of energy-conscious design, environmental energy considerations at the meso scale can and have encompassed larger building agglomerations The new Town of Fermont in Northern Quebec, **Figure 6.5.1.1-3,** is a good case in

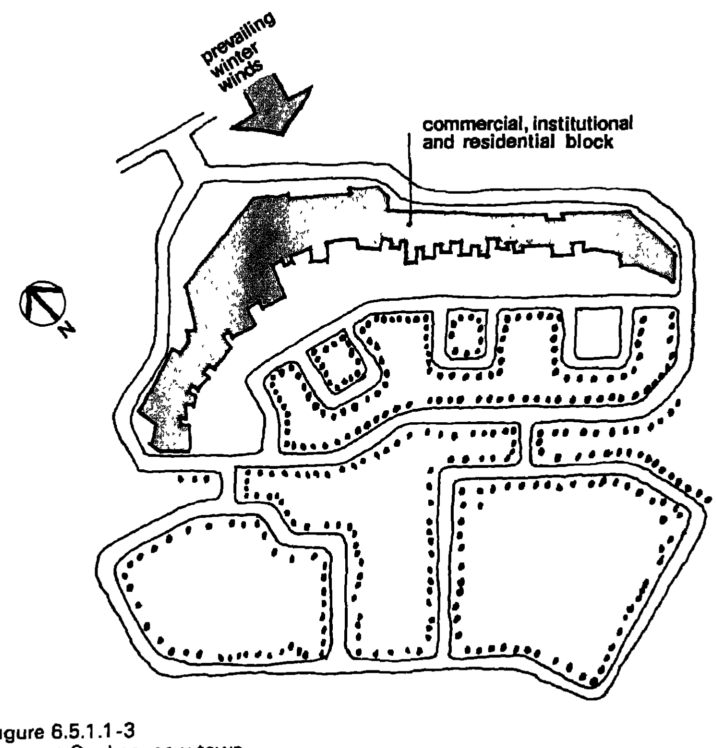


Figure 6.5.1.1-3
Fermont Quebec, new town

point. There, a wind 'barrier' was erected in order to intercept the prevailing winter northeasterlies. This 'barrier' is an architectural complex five stories in height and accommodates most of the town's educational, recreational and commercial facilities. The top of this long linear structure contains apartments. In the lee of the structure is located the lower density housing over a southwest-facing site, gently sloping towards a lake. It is evident that this example incorporates many of the energy-conserving site selection and design principles which we have been discussing.

6.5.1.2 Effect on Solar Radiation

Mention was made earlier, when macro-siting was under consideration, of the overall merit of a traditional grid layout with east-west oriented major streets A little more refinement is called for at the meso scale.

Firstly, the cluster, which we have since used as a generator of energy-efficient land use, is a variant on the cul-de sac rather than on the continuous linear street, not all units can be parallel to each other and identically oriented to the incident sun This is actually a positive feature as their relationship can produce areas protected from the wind and sun traps. Their effect can be enhanced by appropriate treatment of the ground and other exposed surfaces but care must be taken to ensure that the heat which they generate can be moderated by the passage of cooling breezes through the cluster

If that cannot be achieved, especially in Canada's more temperate zones where summer conditions can be aggravating, the old grid arrangement may still be the best arrangement, other things being equal, or at least a 'headless' cluster should be considered, **Figure 6.2.3.2-1**.

Secondly, tall buildings pose a special problem that cannot always be accommodated by the grid, or for that matter the cluster There is the conflict between wind and solar based requirements, in the classic, south-sloping site with predominant winter winds coming from the general northern direction, it might be good from the solar point of view to locate the taller building uphill, so they do not cast any shadows on the lower structures From the point of view of wind this may be a good idea in a Fermont-type arrangement where relatively tall buildings form a continuous wind screen but it may not be so good for taller or discontinuous 'point' buildings, the upper levels of which may find themselves hit by some strong winds near the top of the ridge

Additionally, if such buildings have a central corridor with rows of units on each side only half their users will get any sun, unless the long axis of the 'slab' runs north-south. This may or may not be good for adjacent lower structures, oriented that way, a tall building presents the least obstruction to the noon sun but in the winter it may cast shadows for very long periods of time to the east and west Besides, a building so oriented acts poorly as a screen to predominant winter winds and is itself subject to relatively high air infiltration, an important consideration on the upper stories where wind speeds are higher.

This rather equivocal series of guidelines gives an indication of the complexity of meso-climatic considerations when overall energy savings for a complex of buildings (and land uses) are being sought

These guidelines will necessarily be found ambivalent unless a comprehensive appraisal is made of the particular conditions prevailing at a given site by architects and their collaborators.

6.5.1.3 Anticipated Developments

A discussion of the 'fine-tuning' of environmental measures to maximize energy conservation at the meso scale must come up, sooner or later, against the possibility that the best conceived site and land use plan can be negated or seriously compromised by the actions of neighbouring land users. This is most obvious in the case of 'solar rights', the rights of access to solar radiation. Unfortunately, solar rights are nowhere as legally entrenched as, say, riparian rights that ensure access to water, and very few people have even begun thinking about wind rights. While protection from unwanted diversion of air flows, which may have significant (or even safety) repercussions on neighbouring private or public land uses is difficult to legislate, the path of the sun is predictable and solar incidence on a particular piece of land could be ensured Pertinent regulations at the time of this writing do not exist in Canada, but legislation is being passed in the United States and it is just a matter of time before it comes to this country. Architects would be well advised to maintain a vigil for its passage and to familiarize themselves with the likely geometric building forms that such legislation might prescribe.

In the meantime, architects should learn to protect their own buildings from the incursions of neighbouring building masses. Some rough indication of the relation between solar path and landscape or streetscape have been given here, but there is no real substitute for a thorough and specific simulation in model form of what neighbouring land uses can do to one's proposed building or building complex. Similarly, there is no substitute for wind tests and air flow simulations, again using models In the final analysis, much that has to do with the study of the energy efficiency of land uses at the meso scale, is contained in research that should be part of any acceptable design study

6.6.1 Passenger Movements in the Urban Area

Recent research[1] has highlighted the fact that energy costs associated with transportation infrastructure are often, on a per kilometre travelled basis, of the same magnitude as direct operating costs Table 6.6.1-T_1 summarizes the total energy requirements of passenger travel in urban areas and for interurban travel Although the data have been developed based on a number of assumptions about the types of vehicles and infrastructure and their usage and economic lives it can be seen quite clearly that high capacity transit is the most effective means of conveying passengers in an urban area, while rail and marine transportation are efficient for long distance freight operations Although calculations for the latter consider interurban travel as well as urban travel, facilities in urban

EXAMPLES OF TOTAL ENERGY REQUIREMENTS PER PASSENGER KILOMETRE (KILOJOULES PER PASSENGER KILOMETRE)								
Mode of Transportation	Direct Energy Consumption	Energy Requirement For Energy Production	Vehicle Production Energy	Vehicle Maintenance Energy	Infrastructure Construction Energy	Infrastructure Operations and Maintenance Energy	Total Indirect	Total
URBAN PASSENGER TRAVEL								
Automobile								
—Intermediate Size								
—On Arterial	4981	971	661	412	360	111	2515	7496
—On Expressway	3819	745	661	412	325	47	2190	6009
—Sub Compact Size								
—On Arterial	2657	518	445	341	360	111	1775	4432
—On Expressway	2125	415	445	341	325	47	1573	3698
Bus								
—Small Urban	1820	230	147	247	189	58	871	2691
—Standard Urban								
—On Street	1810	228	140	200	138	43	749	2559
—On-Busway	1526	192	79	169	600	152	1192	2718
Rail Rapid Transit								
—Subway	746	496	114	77	965	218	1870	2616
—Elevated	746	496	114	77	321	218	1226	1972
—Surface	746	496	114	77	234	218	1139	1885
INTER-URBAN PASSENGER TRAVEL								
Automobile								
Intermediate Size								
On Arterial	2325	453	462	288	292	25	1520	3845
-On Freeway	2325	453	462	288	196	20	1419	3744
-Sub Compact Size								
--On Arterial	1328	259	312	239	292	25	1127	2455
—On Freeway	1328	259	312	239	196	20	1026	2354
Bus								
—Inter Urban Coach								
--On Arterial	813	102	47	119	81	52	401	1214
—On Freeway	813	102	47	119	62	51	381	1194
Rail								
—Passenger Train	1281	161	69	138	1824	361	2553	3834
Air								
—CTOL 1200 km	5581	703	66	124	187	310	1390	6971
—STOL 400 km	2498	315	78	230	175	354	1152	3650

Table 6 6 1-T_1
Total energy requirements of passenger travel[3]

areas which encourage the rail and marine movement of freight are advantageous from the overall viewpoint of energy conservation, but may pose severe urban planning problems, such as a proliferation of at-grade railway crossings

Of course the above estimates are based on assumptions: practical considerations including actual operating experience may present a different picture. For example a recent press release[2] by the U.S Secretary of Transportation stated that Amtrack is slightly less energy efficient than the auto and significantly less than the intercity bus based on energy costs per passenger mile when one considers the current number of passengers carried on each mode. On this basis the energy efficiency of buses was approximately 3 5 times that of Amtrack Obviously, the potential efficiency of Amtrack is much higher

Although there appears to be no similar information for personal rapid transit (PRT) systems, it is believed that these are high energy consumers, especially when infrastructure energy requirements are considered

6.6.1.1 Methods to Reduce Energy Consumption

It seems apparent that maximum conservation of energy would result from minimizing the use of the automobile This can be achieved most effectively by legislation and pricing policies. Only a limited amount can result from design and planning initiatives since competing developments will tend to nullify the effect of those which discourage automobile usage

However, on an area-wide basis, there are selected means of reducing energy consumption. These measures include

—promoting car/bus/van pooling efforts
—providing free and ample fringe parking with express bus or rail service for commuters
—increasing general auto occupancy (by reducing available parking at destination, by use of commuter traffic lanes, by legislation)
—restricting auto use in selected zones
—improving transit service.

6.6.1.2 Pedestrian Activity

An area where architects have a greater means of influencing energy consumption is in the method of treating pedestrian movements within and between buildings Studies conducted in Minneapolis and St. Paul[4] indicate the following

—Grade separated pedestrian systems appear to support the goal of a 'compact' downtown, yet encourage longer walking distances
—Above-grade systems have distinct advantages over below grade pedestrian walkways (Table 6.6.1-T_2).
—Above grade, at grade, and below grade elements should be considered compatible components in the overall pedestrian circulation system
—Mechanically assisted connections are imperative system elements for vertical travel.
—Mid-block is the best location for subway bridges and concourses as long as connections to adjacent areas area also possible at this location.

—Climate control is essential.
—Other amenities (such as carpeting, good signing, public washrooms) should be integrated into the pedestrian system wherever appropriate
—Careful engineering is required to minimize bottlenecks
—Skyways should be designed with the user—the pedestrian—in mind at all times, and design should encourage use

Despite some of the foregoing experience, if energy conservation is one of the prime objectives of a design then consideration should be given to eliminating all horizontal pedestrian assist systems Additionally, vertical assist systems should be confined to those movements in excess of two-storey grade changes, clearly marked and attractive stairways can be used as alternatives for short elevator journeys

PEDESTRIAN SYSTEMS COMPARED		
	Preferred Pedestrian System	
Considerations	Above Grade	Below Grade
Good personal orientation	☑	☐
Minimum sense of confinement	☑	☐
Proximity to office building employees	☑	☐
Least cost of construction	☑	☐
Minimum disruption to existing buildings or utilities	☑	☐
Ease of system expansion independent of building construction or reconstruction	☐	☑
Minimum cost to control temperature	☐	☑
Ease of direct connection with below-grade transit station	☐	☑
Minimize risk of aesthetic disruption to architecture	☐	☑

Table 6 6 1-T_2
Comparison of above and below-grade pedestrian systems

6.6.1.3 Motorized and Regular Bicycles

Bicycle use, and in selected areas, the use of small motorized cycles as opposed to more costly means of transport, should be encouraged by design practice. These principles include.
—provision of grade separation from heavy motorized networks
—provision of bicycle facilities, such as bicycle racks
—keeping grades acceptable
—providing protection from the elements, where feasible.

6.6.1.4 Potential Strategies

The Government of Ontario[5] has listed a set of potential urban transportation conservation strategies which could bring about reductions in energy consumption in the near future These, like many of the realistic strategies for transportation energy conservation, depend more upon legislative initiative than design factors although the latter can be incorporated into programs which utilize the strategies. These strategies are shown in **Table 6.6.1-T_3**

CONSERVATION STRATEGIES		
	Short Term	Medium Term
Operations	stop sign elimination vehicle performance inspection optimization of transit frequencies	exclusive HOV* streets flexible transit—union rules
Car/Van Pools	voluntary employer programs HOV* ramps and lanes	mandatory employer programs jitney pickup
Auto Restraints	parking rate increase fuel price increase	parking elimination rationing 2nd and big car tax penalty
Transit Incentives	frequency increase express service special generator service	bus corridors selective investment in light rail transit
Travel Reduction	conservation education program 4-day work week telecommunications	limit road and transit expansion user pay on transit
Land Use	living closer to work	compact and mixed development self-sufficiency of satellite communities
Other	procurement practices (i e purchasing of energy efficient vehicles)	
*High Occupancy Vehicle		

Table 6 6 1-T_3
Potential urban transportation conservation strategies [6]

6.6.2 Goods Movements in the Urban Context

Centralization of services and amenities will, in general, lead to reduction in energy consumption but may not be an admirable goal in terms of other development objectives.

However there are services which could benefit from some form of centralized management, most noticeably urban goods movements In Canada this usually translates into centralized management of trucking facilities Urban trucking activity relates closely with population[7] there being about one and one half daily truck kilometre of activity per urban resident Clearly any opportunity to reduce the two million or so daily truck-km in cities such as Montreal and Toronto should be grasped. In general, light trucks contribute about 65% of this total, medium sized trucks about 24% and heavy trucks 10%. Total energy requirements per tonne kilometre for various freight transportation modes are shown in Table 6.6.2-T_1.

Of several possible methods of reducing energy costs associated with urban truck movements two general approaches are relevant to architects and urban planners. One is consolidation of receiving and delivery while the other is improved design for truck movements and loading

EXAMPLES OF TOTAL ENERGY REQUIREMENTS PER TONNE KILOMETRE (KILOJOULES PER TONNE·KILOMETRE)								
Mode of Transportation	Direct Energy Consumption	Energy Requirement For Energy Production	Vehicle Production Energy	Vehicle Maintenance Energy	Infrastructure Construction Energy	Infrastructure Operations and Maintenance Energy	Total Indirect	Total
FREIGHT TRAVEL								
Truck								
—Urban Van*								
—Arterial	5784	1128	617	759	556	171	3231	9015
—Expressway	4569	891	617	759	501	72	2840	7409
—Inter-Urban Tractor Trailer								
—Arterial								
—Carrying Lighter Material	2458	309	83	253	237	25	907	3365
—Carrying Heavier Material	1518	192	47	142	133	14	528	2046
—Freeway								
—Carrying Lighter Material	2458	309	83	253	166	21	832	3290
—Carrying Heavier Material	1518	192	47	142	93	12	486	2004
Railway								
—General Freight	868	109	158	123	320	27	737	1605
—Bulk Freight	362	46	40	38	98	7	229	591
Air Cargo								
—Boeing 707 Freighter	20702	2609	189	310	148	258	3514	24216
Marine								
—Self-Unloading Bulk Laker	118	15	15	3	76	8	117	235
Slurry Pipeline (16 500 000 t/a)								
—320 km Line	377	251	—	—	72	231	554	931
—1600 km Line	238	158	—	—	56	46	260	498

*For the urban van, the requirements are expressed on a vehicle kilometre basis as no assumptions as to average load were made

Table 6 6 2-T_1
Total energy requirements of freight travel [8]

6.6.2.1 Consolidation

To date consolidation has met opposition for a variety of reasons but, even on a small scale—for example consolidating all delivery and receiving areas for a new mixed use development—it warrants serious consideration The larger application of consolidation, where all major truck movements are focused on one or a series of centralized facilities, present serious difficulties, such as legal problems, (associated with damage, theft and vandalism) which would have to be overcome

6.6.2.2 Improved Delivery

A second means of improving urban goods delivery is to optimize trucking operations. Provision of truckways within basement or parking garage areas, or on their own routes, should be considered in the design of substantial developments. Table 6.6.2.2-T_1 illustrates in a general manner the problems and potentials of urban goods movement.

URBAN GOODS MOVEMENT PROBLEMS AND POTENTIALS			
Components	CBD Distribution	Local Distribution	Terminal Intercity Line Haul
Problems	Congestion	Congestion	Inadequate Terminals—terminal congestion
	Car—bus—truck—pedestrian conflicts	Truck travel through residential neighbourhoods	Proliferation of terminals
	Inadequate loading space—on and off street	Proliferation of lightly loaded vehicles (less than truckload)	Poor rail—truck interchange
	Inadequate building design (i e elevators)		Land-use conflicts
	Cargo security		ICC Commercial zone constraints
Potential Solutions	Car free zones	Truck Routes	Better intermodal terminal design
	Curbside loading zones	Restrict large trucks in residential areas	Expanded commercial zone
	Consolidated shipping and receiving areas in office buildings	Traffic engineering—management	Shipment consolidation and transportation facility centers
	Urban redevelopment	Curb parking restrictions	Planned industrial parks
	Basement truck streets	Dial-A-Bus package deliveries	Truckways
	Traffic engineering—management	Truckways	Truck ramps to freeways
	Zoning by law changes re elevators and dock space	Provision for loading in shopping centers	Containerization—unitized cargoes
	Relocation of warehousing and wholesaling areas		
	Improved dock designs		
	Parking lot use for delivery trucks		

Table 6.6.2.2-T_1
Urban goods movement, problems and potentials [9]

6.6.2.3 Conservation Measures

Clearly energy can be conserved in the urban transportation field by a variety of methods—physical and legislative, as well as by incentive schemes Some measures which can achieve energy conservation in road transportation together with an indication of the elements within the transportation system and how they are affected is shown on **Table 6.6.2.3-T_1**.

Nitkin[10] has proposed a set of iniatives which could influence the volume, frequency and length of travel and result not only in reduced energy consumption but also satisfy certain desirable municipal objectives These initiatives are outlined in **Table 6.6.2.3-T_2**.

6.6.3 Transportation Networks

A large volume of research has been conducted on the theoretical aspects of networks[11, 12] some of which would seem to have practical application. For example, Holroyd[13] showed that for cities with circular geometry, the mean length of journies between independent origins and destinations is between 14 and 27% shorter following a polar (ring and radial) network than on a rectangular network. The importance of this finding is somewhat diminished when it is appreciated that design can effectively ensure that origins and destinations are not 'independent' but can be grouped into patterns which minimize journey distances irrespective of network type.

Measure	INDICATION OF AFFECTED ELEMENT WITHIN THE TRANSPORT SYSTEM										
	Reduce trips	Reduce vehicle travel per trip	Reduce vehicle trips	Improve petroleum efficiency of some vehicles	Transfer travel to more petroleum efficient vehicle	Transfer travel to non-petroleum using vehicle	Economy and cost effectiveness	Environment	Safety	Implementation	Continuing effectiveness
Comprehensive											
Curfew	T,O	T,O	T,O	Nil	Nil	Nil	–	?	+	+	-
Driving day ban	T,O	T,O	T,O	Nil	Nil	Nil	–	+	+	+	-
Control inefficient use of vehicles											
Parking regulation	T,O	?	T,O	T,O	T,O	T,O	?	+	+	+	?
Disc for car into city	T,O	T,O	T,O	?	T,O	T,O	?	+	?	?	+
Close roads to inefficient vehicles	T,O?	T,O	T,O	Nil	Nil	Nil	+	+	Nil	?	?
Control or influence fuel purchase											
Ration	T,O	T,O	T,O	O,V	T,O,V,L	T,O,V,I,L	–	+	–	+	-
High scarcity market price	T,O	T,O	T,O	O,V	T,O,V,L	T,O,V,I,L	?	+	–	+	?
Increasing price by tax	T,O	T,O	T,O	O,V,I	T,O,V,I,L	T,O,V,I,L	+	+	=	?	+
Develop non-petroleum fuel	Nil	Nil	Nil	Nil	Nil	V,I	+	+	=	?	+
Control or influence vehicle efficiency											
Increasing vehicle efficiency required	Nil	Nil	Nil	Nil	V	V	?	+	?	?	+
High tax on inefficient vehicles	T,O	Nil	T,O	Nil	T,O,V	T,O,V	+	+	?	?	+
Control or influence use of more efficient mode											
Public transit more attractive	Nil	Nil	T,O	Nil	T,O,I	T,O,I	?	+	+	?	
Pedestrian zones	Nil	T	T,O	Nil	Nil	Nil	+	+	?	?	
Bicycle and footpaths	Nil	T,I	T,I	Nil	T,I	T,I	+	+	–	?	
Ride sharing incentives	Nil	T O	T,O,I	Nil	Nil	Nil	+	+	=	+	
Ride on demand, jittney dial-a-ride	Nil	T	?	Nil	?	?	?	?	=	?	
Traveller and operator education	T,O	T,O	T,O	T,O	T,O	T,O	+	+	?	+	
Control and management of roadway and infrastructure											
Improved traffic management	Increase	Nil	Increase	T,O,I	Nil	Nil	+	+	+	+	
Bus and ride sharing lanes	Nil	T,O,I	T,O	O,I	Nil	Nil	+	+	=	?	
Truckloading zones and facilities	T,O,I	T,O,I	T,O,I	T,O,I	Nil	Nil	+	+	+	?	
Truck regulation	T,O	T,O	T,O	Nil	T,O	Nil	?	+	+	?	
Freight consolidation	T,O,I	T,O,I	T,O,I	Nil	T,O,I	Nil	+	+	–	?	

T = Traveller or transport producer
O = Operator of vehicle
V = Vehicle
I = Infrastructure through which vehicle moves
L = Land uses and arrangements of activities

Estimates of magnitude of impacts
\+ (advantage or improvement)
– (undesirable or difficult)
= (no effect)
? (undetermined or highly varied)

Figure 6 6 2.3-T,
Effects of measures to achieve energy conservation in road transportation [14]

POTENTIAL MUNICIPAL, SOCIAL AND STRUCTURAL PLANNING INITIATIVES
Land Use Planning
Integration employment, residential nodes with transit
Compact (integrated, mixed, higher density) land use
Compatible jobs in residential areas
Zone for higher overall densities
Limit number and location of parking spaces
Multiple and sequential use of transportation rights-of-way
Complete thoroughfares on local streets
Mixed use zoning of structures
Neighbourhood activity centres (nodal concentration commercial activities)
Reduced parking space requirements for multi-occupancy buildings
Social Planning
Near urban activity centres, parks
Nonprovision of certain recreational facilities
Multiple use of schools, municipal buildings in off peak hours
3 or 4 day work week experimental programs
Early retirement programs
Operational Planning
Speed limit enforcement
Special events generator transit service
High speed transit service in high density corridors
Strategic timing, phasing of structural investment
Vehicle performance testing (public, municipal)
Increase parking rates, recreation fees
Public education program on conservation
Elimination of stop signs
Low transit fares
Neighbourhood to node feeder transit programs
Auto free zones
Exclusive high occupancy vehicle lanes, corridors
Administration
Municipal taxes on nonresident employees at place of work
Risk analysis of urban transportation (expressway) investment
Gasoline price surcharges
Flexible transit operator rules
Telecommunications substitution program testing
Increased property tax on multiple garage dwelling units
Selective improvement or spot rezoning compatible with existing transportation system
Tax rebate for living close to work
Tax credit, loan guarantees for van pool program
Car/Van pool program promotion

Table 6.6 2 3-T_2
Initiatives reducing energy consumption as well as satisfying certain municipal objectives.[15]

ESTIMATED FUEL AND COST SAVINGS FOR LOUISIANA'S SEVEN MAJOR CITIES WITH EXTENSIVE TRAFFIC SIGNAL COORDINATION

City	No of TOPICS Signals		Field Study Results		Estimated Daily Signal Stops			Total Time Saved/Day, Minutes	Savings Per Day		Savings Per Year	
	Network Total	Proposed Co-ordinated	% Signals Causing Stops	Av Delay Min / Stop	Today's Totals	Signal Coordination			Fuel in Litres	Costs in Dollars	Fuel in Litres	Costs in Dollars
						Eliminated	Less Delay					
Alexandria	90	80	50 5	0 37	601 203	324 503	276 700	131 134	13 000	9 409	4 810 000	3 434 285
Baton Rouge	260	200	66 0	0 50	2 661 878	1 668 826	993 052	1 003 232	31 900	65 712	21 880 000	23 984 880
Lafayette	100	72	49 6	0 42	786 810	420 287	366 523	209 508	18 900	15 032	6 303 000	5 486 680
Lake Charles	134	72	53 4	0 43	625 064	334 141	290 923	172 773	15 300	12 396	5 571 000	4 524 540
Monroe	126	72	44 8	0 42	638 385	281 747	356 638	150 431	13 000	10 793	4 772 000	3 939 445
New Orleans	508	309	45 8	0 46	5 394 800	2 697 400	2 697 400	1 591 466	131 000	114 188	47 869 000	41 678 620
Shreveport	292	252	24 7	0 33	1 378 450	137 845	—	34 461	5 000	2 473	1 771 000	902 645
Totals	1 510	1 057			12 086 590	5 864 749	4 981 236	3 293 005			101 676 000	83 951 095

Table 6.6.3-T_1
Estimated fuel and cost savings in Louisiana with extensive traffic signal coordination

It has also been acknowledged that a honeycomb network has major advantages, including operating advantages, since there are only three links to each node, which are easier to control than four link nodes

6.6.3.1 Energy Conserving Strategies

For a given urban road network there are many strategies which reduce energy consumption (as well as others which increase it, such as four-way STOP control) For an existing network, probably the most effective energy conservation strategy is the application of traffic signal control methods Louisiana[16] estimated that implementation of signal control coordination in seven major cities resulted in annual savings of nearly $84 million. **Table 6.6.3-T$_1$** indicates details of the estimates

Another study[17] indicates that one-way street systems conserved energy over two-way systems The advantages of progressive signal systems, increased capacity etc , outweighed slightly longer journey distances

RESULTS OF ONE-WAY VS. TWO-WAY STUDY				
	Peak		Off-Peak	
	One-Way	Two-Way	One-Way	Two-Way
Stops/Vehicle · km	3 16	2 64	3 23	2 52
Delay, min/(vehicle · km)	2 00	1 31	1 93	1 41
Average Speed (km/h)	18 06	22 55	18 31	21 71
Fuel Consumption (km/L)	3 62	4 10	3 61	4 02

Table 6.6 3-T$_2$
Energy conservation and street patterns

6.6.3.2 Compact Planning

With some notable exceptions, recent new town planning in Canada unfortunately seems to indicate that even when beginning from scratch, traditional forms of development and supporting infrastructure predominate, perhaps because of economic, legislative, topographical and other constraints.

One exception to this generalization would be the proposed March Township development in Ontario. This proposal, **Figure 6.6.3.2-1** incorporates some of the principles of compactness and density previously discussed in this section.

Energy efficient, semi detached houses, grouped houses and garden apartments on a simple and continuous grid layout permit reduced road lengths compared with random and conventional suburban planning. Residential streets running east-west provide the houses along them with the maximum opportunity for solar collection. In combination with a reasonable density, simplified street patterns, without cul-de-sacs, also help make mini-bus systems viable Additional benefits accruing to the community include the facilitation of street maintenance, service vehicles, snow clearance and police, fire and ambulance services.

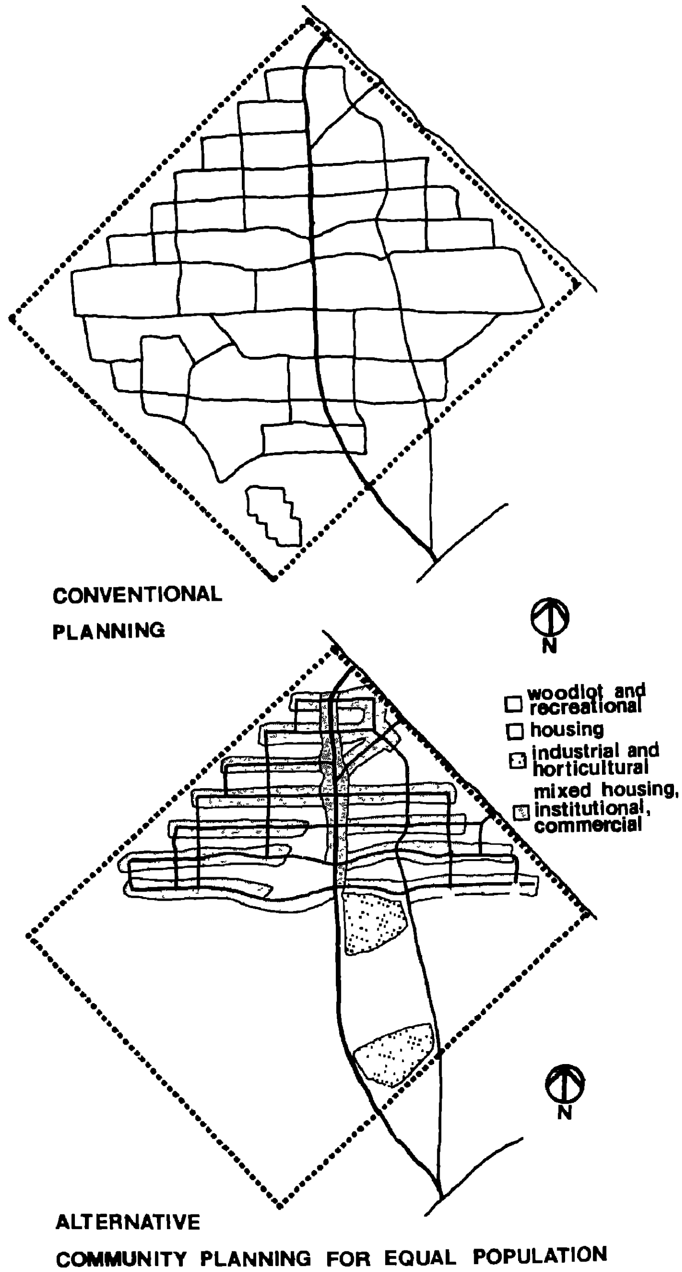


Figure 6 6 3 2-1
Conventional town plan and alternative plan for town in March township[18]

6.6.4 Transportation Energy Costs and Urban Form

Although there have been attempts to quantify the energy costs of urban sprawl it only seems reasonable to state that, generally, per capita energy consumption decreases as gross building density increases, although one study[19] indicated that energy consumption again increased at the core of population concentrations.

Further there is good reason to believe[20] that the sprawl pattern of urban form is less energy efficient than other planned patterns.

However, no consensus exists as to the most efficient pattern and shape but it has been suggested that the average resident of New York City uses half as much energy as the average American.

Several years ago, the Regional Planning Commission of south-eastern Wisconsin[21] investigated the transportation costs related to a high density plan and an urban sprawl plan The former plan was based upon an average population density in the urbanized area of 1700 persons per square kilometre while the urban sprawl plan had a density of 1000 persons per square kilometre.

The results of the study are shown on **Table 6.6.4-T$_1$** where it can be seen that the higher density plan would result in savings in transportation operating costs of some $2 billion per day as well as providing other infrastructure benefits

Although dealing more with capital and operating costs and land costs, a report[23] prepared by the Real Estate Research Corporation also confirmed that higher density development brings about increased energy efficiencies and concluded that medium, as opposed to low density development, reduced natural resource consumption

COMPARISON OF THE TRANSPORTATION OPERATIONS OF A CENTRALIZED PLAN AND A SPRAWL LAND USE PATTERN		
	Recommended Land Use Plan	**Unplanned Land Use Alternative**
Vehicle hours of travel	926,000 h/d	1,016 00 h/d
Operating costs	$20 34 billion	$22 31 billion
Vehicle kilometres of travel	51 96 million	59 46 million
Land for transportation	172 2 km^2	245 0 km^2
Average population density	1700 persons/ km^2	1000 persons/ km^2
System costs	$2 10 billion	$2 23 billion

Table 6 6 4-T$_1$
Comparison of urban transportation operations at two different densities[22]

6.6.4.1 Recent Studies

A recent report by OECD[24] indicates that little is known at present about the relationships between urban spatial structure, urban transportation networks and energy consumption in urban travel and furthermore studies in this area are scarce However it contained the following information concerning studies which provide some insight into these relationships.

A Stockholm regional planning office study indicated that the lowest cost per apartment, for construction of transportation facilities, is likely in two to three storey building areas since more dense development requires costly parking facilities. However the latter density facilitates the provision of public transit Relative transportation costs for a city of 75,000 were estimated[25] and the resulting cost relationships for three types of housing were as follows:

single family dwelling	2.0
row house,	1.5
highrise	1.1

It is believed these relative costs would be similar in Canada.

A Swedish national investigation found that the density and shape of residential development affected the cost of public transportation and that, for equal levels of service, it was twice as costly to operate bus services in towns of the lowest density compared with the most dense studied. The concentration of activities and densities in corridors was also found to favour public transit

A study was conducted in the United States which was based upon the hypothesis that the structure of urban land use and transportation networks can have a very significant effect on energy consumption in urban passenger travel[26] The results of the research suggest that in order to minimize urban transport energy consumption there is a need to control the horizontal spread of cities and to channel development into higher density, nucleated forms While this may be viewed as long-term land use control objective for existing cities and as a design principle for new towns, it may also be interpreted in the shorter term as a criterion for any new construction of elements within the urban infrastructure

The research results also provide useful information regarding certain urban development factors with regard to energy consumption and urban accessibility, as shown in **Table 6.6.4-T_2**.

Contributory Causes Leading To:	
Relatively high energy use	Relatively low energy use
Expansive land-use	Compact land-use
Spread of population, employment	Concentration about central zones of residential and retail activities
Stop and delay automobile traffic	Free flow on street and freeway network
Long work trips	Short work trips
Predominance of automobile in transportation system	Predominance of public transit and foot travel

Table 6 6 4-T_2
Urban development factors to be considered in formulating energy conservation policies

6.6.4.2 Settlement Patterns

Although it is difficult to synthesize all the studies and their conclusions, Chibuk[27] believes that if the population size and distribution can be managed, then the most efficient pattern appears to be one of small to medium sized compact, rectangular or concentric settlements arranged in a polynucleated fashion However, if population size and distribution cannot be as effectively managed, then the linear pattern or a concentric one would be the energy efficient choice Contiguous and continuous shapes, under such a condition, are considered to be more energy efficient than discontinuous and dispersed shapes (characterized by sprawl and leapfrogging).

The effect such urban forms would have on land values, building and infra-structural costs as well as a host of other factors remains for investigation elsewhere

6.7 Landscape

6.7.1 Energy-Conserving Considerations

The influence of vegetation and topography on general climatic effects was discussed in **Section 2.1.4** and summarized in **Table 2.1.4.1-T_1**. The correlation between the nature of a surface, for example, and temperature, humidity, cloud cover and radiation was noted. Similarly, reference was made to the role of elevation in relation to these considerations and also to rainfall and snowfall

While the means at our disposal to modify the macro-climatic conditions referred to are virtually non existent we can, and do, have an influence at smaller scales, either deliberately or otherwise. The urban heat island, **Section 2.1.5**, for instance, is an illustration of meso-climatic changes resulting from the design and constructional characteristics of human settlements.

However, it is at the scale of the single building or small grouping where the beneficial modification of climate can be most easily achieved. Appropriate building design and siting in conjunction with related landscaping provide the means by which the micro climate can be improved and the energy requirements for the heating and cooling of buildings lessened

It must be recognized that even at this small scale there are limitations; the overall weather pattern cannot be changed and planting requires a number of years to reach mature growth, moreover replacement may sometimes be necessary.

Nevertheless, the contribution which landscaping can make to energy-conserving design is considerable, whether by protecting a building from the effects of climate or by making it more accessible to them Some of the ways in which it can provide a measure of control over solar radiation, wind, precipitation and humidity are reviewed below.

6.7.1.1 Solar Radiation

Trees provide shade. In common with other forms of vegetation, very little of the solar radiation that strikes them will pass through. On warm days the ground temperature of forests has been recorded at 4°C to 5°C lower than outside while the air temperature was 2°C to 5°C lower Pine and spruce forests were in the warmer range and beech in the cooler. In winter, the forest ground temperatures were 1°C to 2°C higher than their surroundings.[1]

The foliage of trees will also intercept re-radiation from surfaces under them, and retain some of the days warmth for enjoyment into the evening if planted in sitting areas adjacent to the house, for instance, **Figure 6.7.1.1-1**.

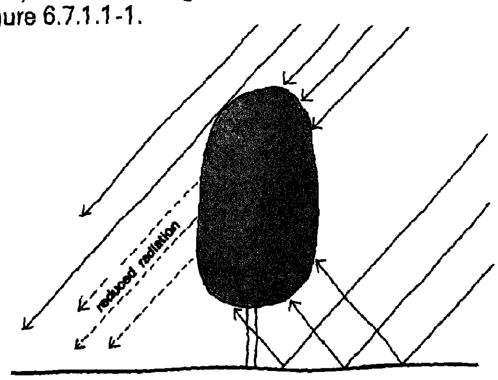


Figure 6.7.1.1-1
Interception of solar radiation by foliage.[2]

6.7 Landscape

.1 Tree selection: The selection of particular species for planting will be determined by the climate and soil in which they must grow and by the type of growth which they produce Growth rate is important and also knowledge of both foliage density and bare branch density is required. Deciduous trees will provide shade for south facing windows in summer and allow winter sun to enter. Evergreens provide year round shading, a desirable feature for west window protection but not so to the south where passive solar collection is desired in the winter Trees can provide effective shading to roofs as well as walls, surface temperature reductions of up to 25°C have been reported on the westerly side of a protected house

Wide short trees shade better in winter and less in summer They should be pruned up, not down, to allow the low angled winter sun through The shade patterns of trees require consideration before, not after, planting and their location should be determined in relation to all requirements, **Figure 6.7.1.1-2.**

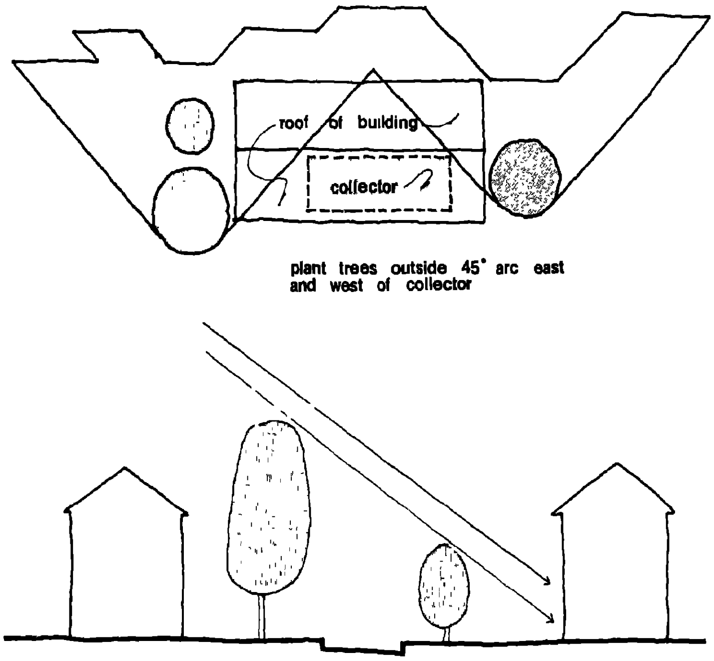


Figure 6 7.1 1-2
Trees and shading [3]

.2 Ground cover: The influence of ground cover is illustrated by the fact that on a sunny day the air temperature over a grassy surface can be 6°C to 9°C cooler than over soil This is because grass has a lower albedo than soil and also provides cooling by transpiration and evaporation [4]

Tests show that natural grass reflects almost three times as much sunlight as artificial turf, their measured surface temperatures being 38°C and 72°C respectively [5] In the same tests the temperature of asphalt was 60°C

Ground cover will also influence frost penetration below the surface. The potential of snow as winter insulation around the base of a building has already been discussed, **Section 2.1**. Planted berms will perform a similar function throughout the year Loose mulches, also, will insulate—in contrast to crushed rock or bricks which radiate additional heat into the soil, a useful property in the winter but not necessarily so desirable in summer

Wood decks provide less reflective surfaces than paving and when elevated permit air movement through and under

6.7.1.2 Wind

Depending on its origin, wind can have a cooling or warming effect The modifying influences of water bodies on air currents have been examined in **Section 2.1.4** of the Handbook Wind speed is up to 20% greater on top of a ridge than on the slopes and there can be similar impact on tall buildings

Air movement affects the comfort of outdoor conditions and influences heat loss from buildings and people.

The human body feels much colder outdoors on a windy day than on a calm one, particularly in winter This is due to the rapid cooling effect produced by the wind which increases body heat loss via convection and evaporation Under extreme conditions the results can be serious and fatal A measure of the combined chilling effect of wind and temperature has been developed by the Atmospheric Environment Service, **Figure 6.7.1.2-1**.

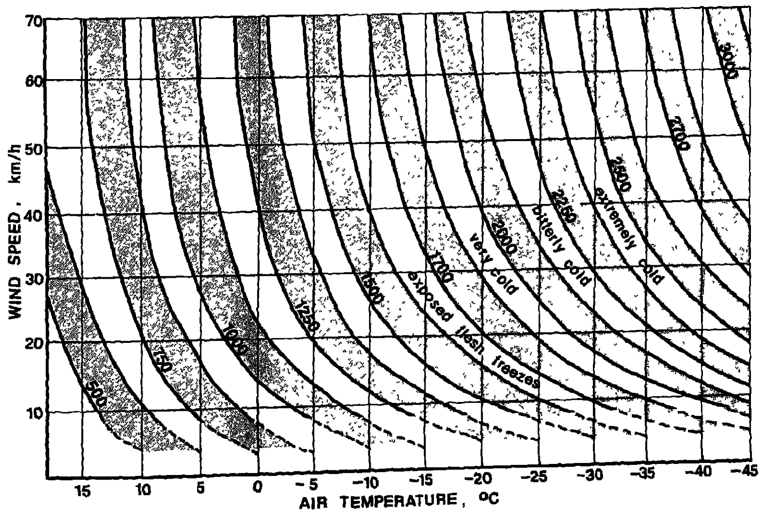


Figure 6 7.1 2-1
Wind chill cooling rates, W/m² [6]

Trees and other elements of landscape can modify considerably the effects of wind on humans and buildings, enhancing those that are benign and reducing those that are less desirable

.1 **Channelling the breeze:** Welcome relief from hot summer weather can be obtained from cooling breezes if they are channelled in the right direction, **Figures 6.7.1.2-2 and 3.**

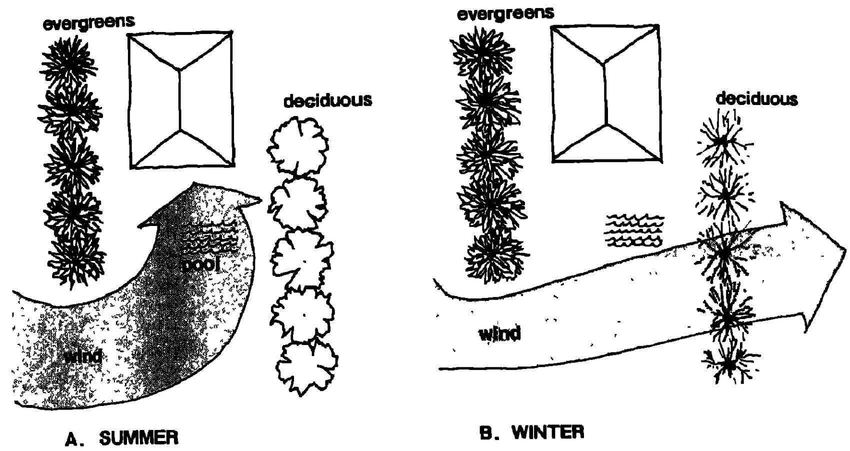


Figure 6 7 1 2-2
Channelling breezes

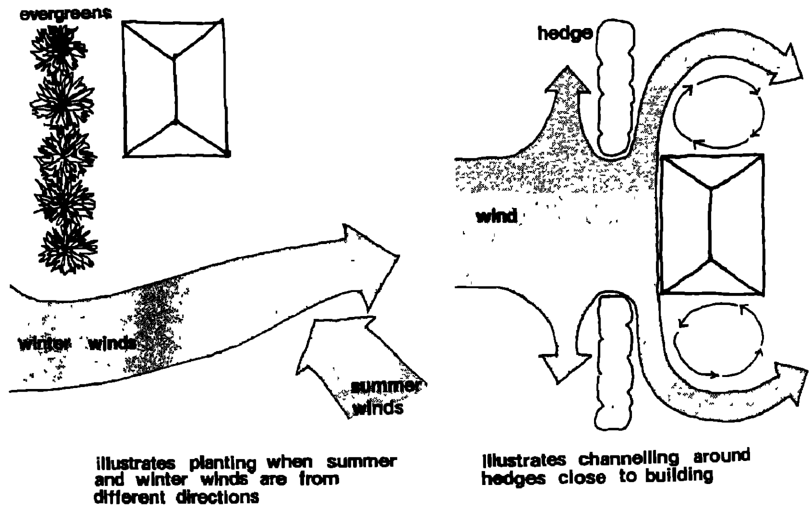


Figure 6 7 1 2-3
Channelling breezes [7]

.2 Windbreaks: The heating load of an unprotected house of conventional construction in a 32 km/h wind can be as much as 2 5 times as great as that in a 5 km/h wind under the same temperature conditions [8] A reduction in wind velocity can be achieved by the planting or construction of wind breaks They provide sheltered areas on their lee side and also, to a lesser extent, on the windward and create perceptible changes in both temperature and wind chill factor, **Figure 6.7.1.2-4.**

If the windbreak is open at the lower level the windward side has little protection, however an opening at the bottom of a fence reduces leeward eddies. A similar result is achieved by natural planting if it is open-textured close to the ground.

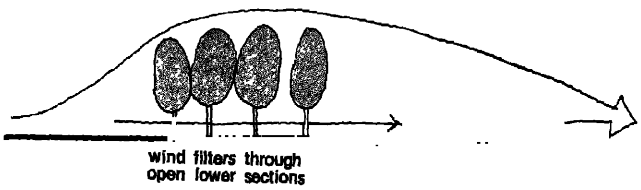


Figure 6.7.1.2-4
Porous windbreak

In general, tree belts produce a large reduction in wind velocities extending much farther to the lee than do solid wind barriers such as walls and fences, Figure 6.7.1.2-5. This is an important consideration when protection is required for a cluster rather than a single building.

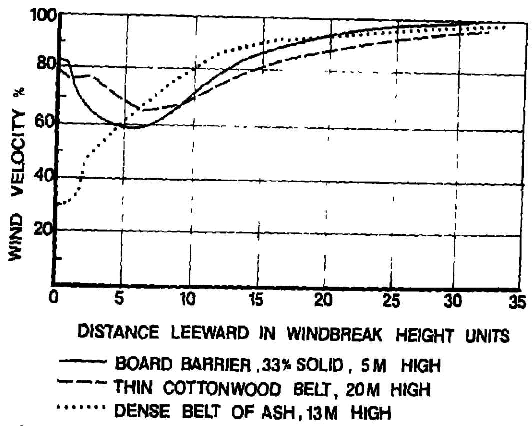


Figure 6.7.1.2-5
Wind velocity at three types of windbreaks [9]

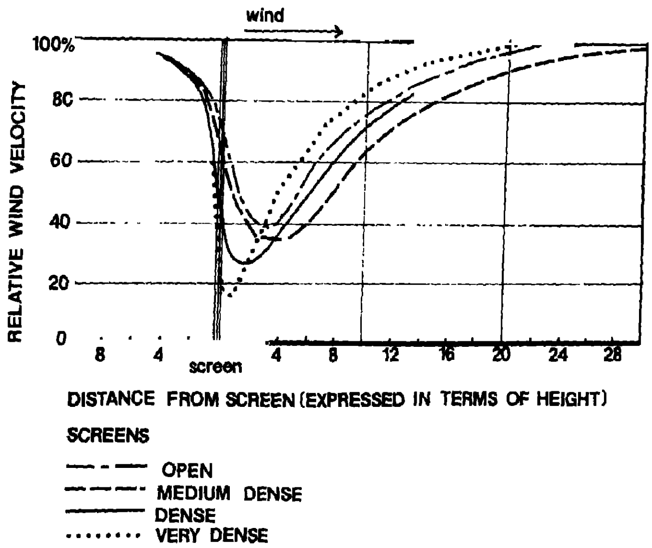


Figure 6.7.1.2-6
The influence of windscreen on the velocity of the wind, measured at a height of 1.4 m over the surface.[10]

As the extent of the protected area is a function of height, the planting of 10 m or 15 m trees compared with the construction of a solid structure of the same height would seem to have many advantages

The greater depth of protection afforded by the medium dense types of windbreak is illustrated in **Figure 6.7.1.2-6** while the larger immediate reduction in velocity provided by the denser type is also shown A too dense shelter belt can create excessive turbulence leeward, **Figure 6.7.1.2-7**.

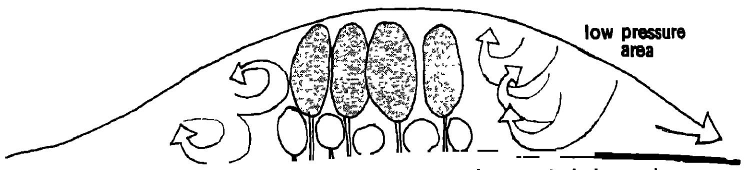


Figure 6.7 1 2-7
Dense windbreak, turbulence pattern

Multiple layers of planting provide the opportunity to intersperse low level vegetation with trees to reduce the velocity of the through flow of wind near to ground level, if desired

Earth berms will also provide wind shielding for individual buildings or groupings, in addition their south faces can be used for the mounting of solar collectors and the windward or north walls of buildings can be built into them for added protection When used in conjunction, plant and land forms can provide greater protection than could be achieved by either separately, **Figure 6.7.1.2-8** Care must be taken when planting on a slope not to impede air flow sufficiently to cause build up of cold air on the lower slope or to create frost pockets, **Figure 6.7.1.2-9**.

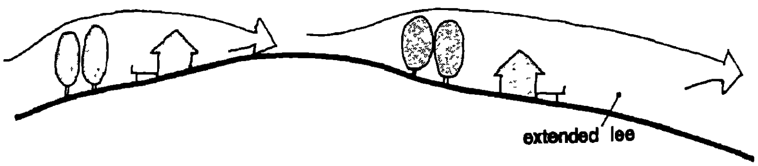


Figure 6.7 1.2-8
Wind protection from combination of planting and land forms [11]

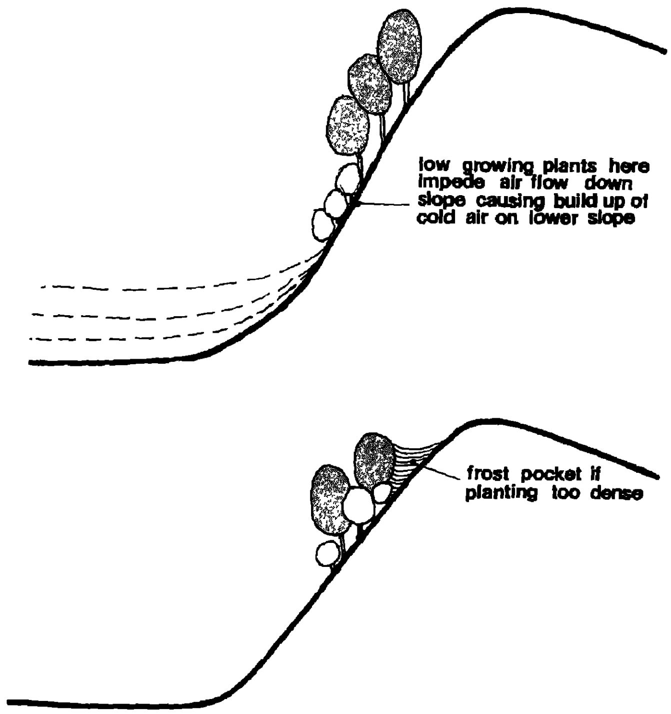


Figure 6.7.1.2-9
Effect of planting on slopes

At the micro scale, planting close to the exterior walls will create a dead air space which could have useful insulation value, particularly on the north side of a building, Figure 6.7.1.2-10.

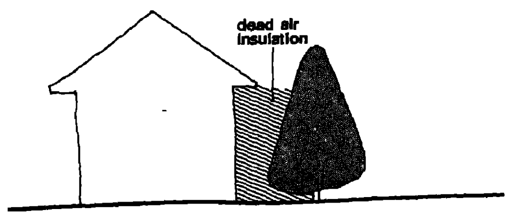


Figure 6 7 1 2-10
Insulating effect of planting adjacent to building

.3 **Snow drifting control**: Snow is deposited where there is no shelter, where wind velocity is reduced or when the wind flow is changed or blocked by an obstruction, Figure 6.7.1.2-11.

The effect of wind breaks on wind speed has already been noted and the flow diagrams previously illustrated have their counterpart in the seasonal snow drift patterns The turbulence or increased wind velocity created by fence, hedge or shelter belt creates a localized scouring effect, Figure 6.7.1.2-12 and 13. Solid fences or planting produce drifts on both sides while in an open structure the drifting is to the leeward.

The most suitable trees for this purpose are those which retain a high density from the ground to full height throughout the winter Structurally, they must be able to carry a substantial snow load

which can accumulate over several months. Evergreens or deciduous trees with small branches are the most effective Trees which are open at their lower sections should be augmented by shrubs, keeping in mind the potential turbulence referred to earlier

Snow tends to accumulate on the lee side of hills and embankments and these should not be used for building or access routes However, if snow-free areas are required in these locations a blower fence, or jet roof, which channels and accelerates the wind flow can provide protection for a limited distance, **Figure 6.7.1.2-13**. Similarly gaps in planted snow screens will also concentrate wind stream

It should not be overlooked that the snow itself can be turned to advantage if the equipment and space are available Snow piles can be as effective as other kinds of barriers, naturally they can only be built after a certain amount of snow has already fallen

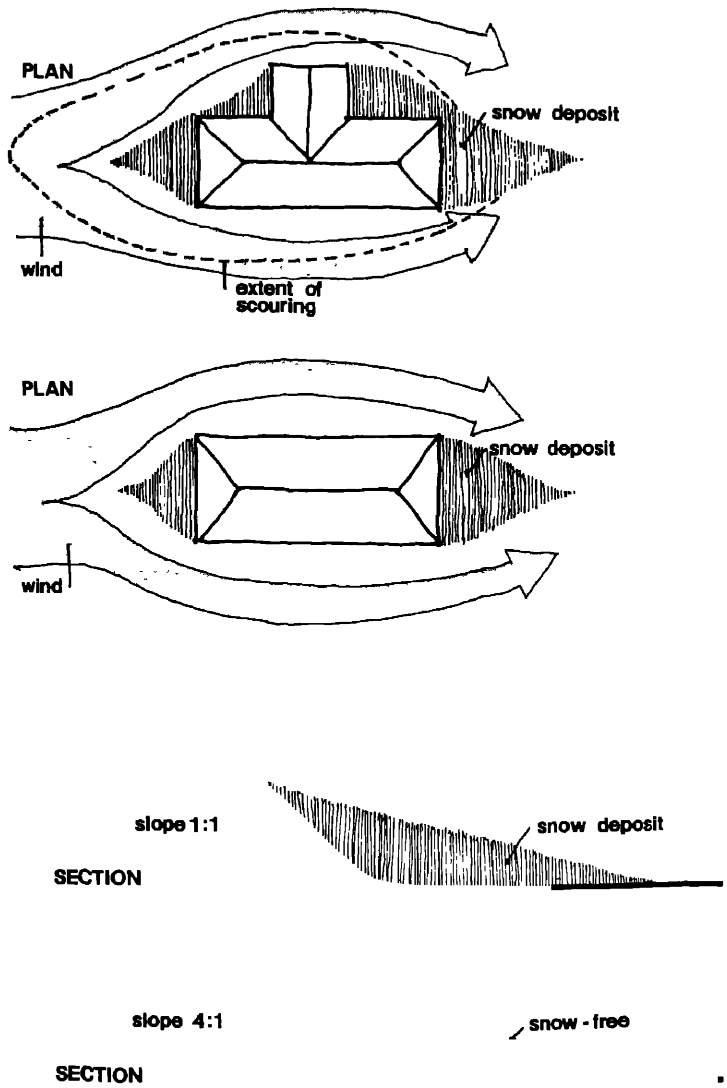


Figure 6 7.1.2-11
Snow deposit patterns

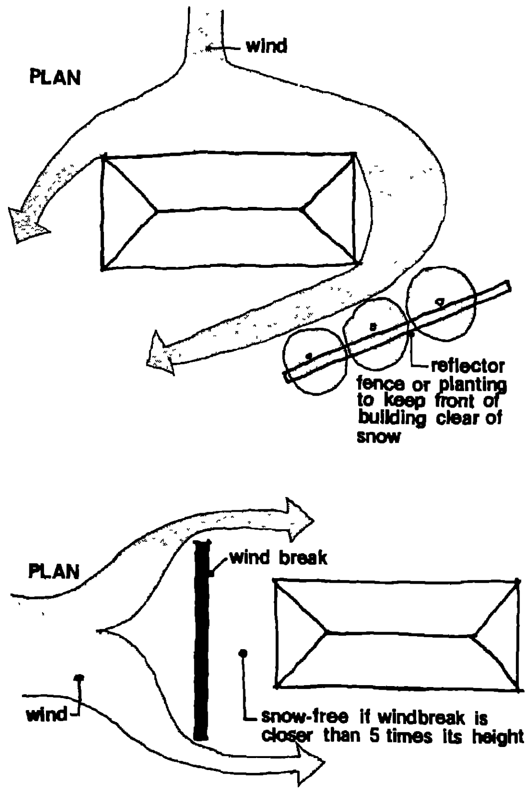


Figure 6.7 1 2-12
Windbreaks, scouring patterns

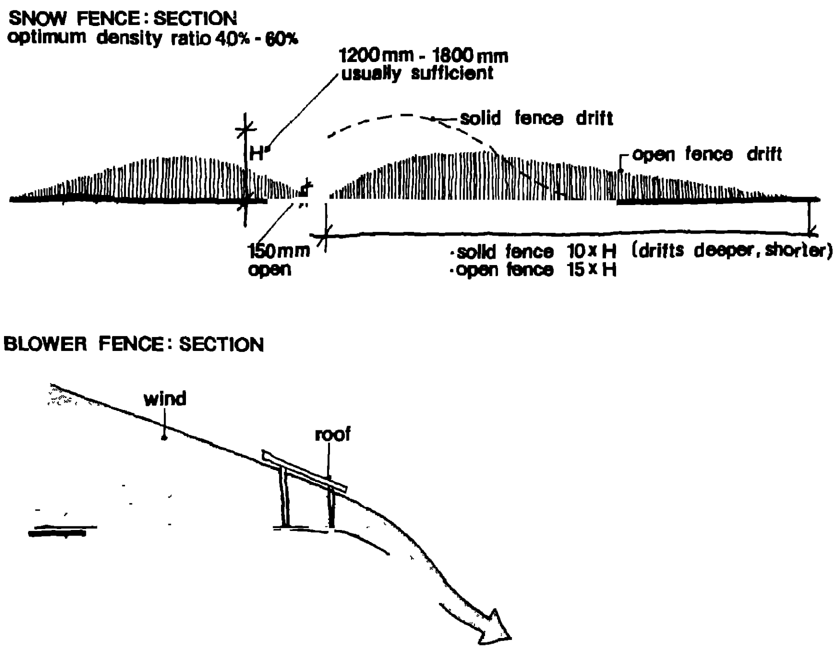


Figure 6.7.1 2-13
Snow fences, vertical and blower types [13]

6.7.1.3 Precipitation

Planting shelters the earth from rain and also induces precipitation in the form of dew.

.1 **Rain**: Not all of the rain that falls on the vegetative canopy reaches the ground Studies by Beale et al show that the actual percentage varies with species. Leaves which have a greater number of sharp angles trap more rainfall than those with less, consequently only 60% falling on a pine forest reaches the ground while hardwood permits 80% penetration Orvington records that in light rainfall conifers retain as much as five times the quantity of water as broad leafed trees [14]

.2 **Fog and Dew**: It is reported that up to ten times as much fog water, and equal quantities of dew, are deposited on a forest as on an open field In Hokkaido, Japan, forests are relied upon to prevent invasions of sea fog Needle-leaved trees without lower branches were found to be most effective for this purpose [15]

Dew forms when atmospheric water vapour is condensed on the exposed surfaces of vegetation and earth which has been cooled by outgoing nocturnal radiation. On trees it is deposited chiefly on the upper surfaces of their canopies and the amount deposited decreases rapidly as the distance from the outer surface of the crown increases It has been calculated that dew accounts for 18% of the annual precipitation in the United States [16]

6.7.1.4 Humidity

Transpiration and evaporation from a large sized tree can be as much as 8000 L in a single day An acre of turf will lose approximately 9600 L according to Michigan State University studies Recordings taken in forests have indicated relative humidity levels 3% to 5% higher than those in adjacent areas outside [17] As noted earlier the tree canopy reduces the penetration of solar radiation so that there is a consequent reduction in the rate of evaporation in planted areas

In combination, these circumstances help to stabilize diurnal temperatures, minimizing their range in comparison with those in surrounding locations

6.7.1.5 Summary

Elaboration of the foregoing will be found in many sources some of which are included in the attached bibliography in addition to those referenced in the text. Frequently, available studies relate to the behaviour of landscaping elements in isolation, for instance wind tunnel testing of individual wind breaks In practice, their performance will often be influenced by adjacent physical features, building forms and site characteristics For this reason, when considering a particular project it is necessary to move from the general to the particular and undertake testing and analysis appropriate to the specific conditions which prevail and also, as far as possible, to those which are anticipated.

Unlike the building, landscaping is ever changing, day by day and seasonally, but it is also predictable. It is an essential constituent for the creation of an indigenous, energy-conserving architecture

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7.0 Energy Economics and Life Cycle Costing

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7.6 Examples

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7.6.4 Example—Annualized Values and Evaluation of Alternatives with Unequal Lives	"
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7.6.6 Example—Sensitivity Analysis	"
7.6.7 Example—Depreciation, Mortgage Payments, Income Tax and Rate of Return on Investment	"

Text References

*Hanscomb Roy Associates

8% INTEREST RATE						
Year	A SCA	B SPV	C UCA	D USF	E UCR	F UPV
1	1 080	0 9259	1 000	1 0000	1 0800	0 926
2	1 166	0 8573	2 080	0 4808	0 5608	1 783
3	1 260	0 7938	3 246	0 3080	0 3880	2 577
4	1 360	0 7350	4 506	0 2219	0 3019	3 312
5	1 469	0 6806	5 867	0 1705	0 2505	3 993
6	1 587	0 6302	7 336	0 1363	0 2163	4 623
7	1 714	0 5835	8 923	0 1121	0 1921	5 206
8	1 851	0 5403	10 640	0 0940	0 1740	5 747
9	1 999	0 5002	12.490	0 0801	0 1601	6 247
10	2 159	0 4632	14 490	0 0690	0 1490	6 710
11	2 332	0 4289	16 650	0 0601	0 1401	7 139
12	2 518	0 3971	18 980	0 0527	0 1327	7 536
13	2 720	0 3677	21 500	0 0465	0 1265	7 904
14	2 937	0 3405	24 220	0 0413	0 1213	8 244
15	3 172	0 3152	27 150	0 0368	0 1168	8 559
16	3 426	0 2919	30 320	0 0330	0 1130	8 851
17	3 700	0 2703	33 750	0 0396	0 1096	9 122
18	3 996	0 2502	37 450	0 0267	0 1067	9 372
19	4 316	0 2317	41 450	0 0241	0 1041	9 604
20	4 661	0 2145	45 760	0 0219	0 1019	9 818
21	5 034	0 1987	50 420	0 0198	0 0998	10 020
22	5 437	0 1839	55 460	0 0180	0 0980	10 200
23	5 871	0 1703	60 890	0 0164	0 0964	10 370
24	6 341	0 1577	66 770	0 0160	0 0950	10 530
25	6 848	0 1460	73 110	0 0137	0 0937	10 680

Table 7 0-T_1
8% Interest rate

10% INTEREST RATE						
Year	A SCA	B SPV	C UCA	D USF	E UCR	F UPV
1	1 100	0 9091	1 000	1 0000	1 1000	0 909
2	1 210	0 8264	2 100	0 4762	0 5762	1 736
3	1 331	0 7513	3 310	0 3021	0 4021	2 487
4	1 464	0 6830	4 641	0 2155	0 3155	3 170
5	1 611	0 6209	6 105	0 1638	0 2638	3 791
6	1 772	0 5645	7 716	0 1296	0 2296	4 355
7	1 949	0 5132	9 487	0 1054	0 2054	4 868
8	2 144	0 4665	11 440	0 0874	0 1874	5 335
9	2 358	0 4241	13 580	0 0736	0 1736	5 759
10	2 594	0 3855	15 940	0 0628	0 1628	6 144
11	2 853	0 3505	18 530	0 0540	0 1540	6 500
12	3 138	0 3186	21 380	0 0468	0 1468	6 814
13	3 452	0 2897	24 520	0 0408	0 1408	7 103
14	3 797	0 2633	27 980	0 0358	0 1358	7 367
15	4 177	0 2394	31 770	0 0315	0 1315	7 606
16	4 595	0 2176	35 950	0 0278	0 1278	7 824
17	5 054	0 1978	40 540	0 0247	0 1247	8 022
18	5 560	0 1799	45 600	0 0219	0 1219	8 201
19	6 116	0 1635	51 160	0 0196	0 1196	8 365
20	6 727	0 1486	57 280	0 0175	0 1175	8 514
21	7 400	0 1351	64 000	0.0156	0 1156	8 649
22	8 140	0 1228	71 400	0 0140	0 1140	8 772
23	8 954	0 1117	79 540	0 0126	0 1126	8 883
24	9 850	0.1015	88 500	0.0113	0 1113	8 985
25	10 840	0.0923	98 350	0 0102	0 1102	9 077

Table 7.0-T_2
10% Interest rate

12% INTEREST RATE

Year	A SCA	B SPV	C UCA	D USF	E UCR	F UPV
1	1 120	0 8929	1 000	1 0000	1 1200	0 893
2	1 154	0 7972	2 120	0 4717	0 5917	1 690
3	1 405	0 7118	3 374	0 2963	0 4164	2 402
4	1 574	0 6355	4 779	0 2092	0 3292	3 037
5	1 762	0 5674	6 353	0 1574	0 2774	3 605
6	1 974	0 5066	8 115	0 1232	0 2432	4 111
7	2 211	0 4523	10 090	0 0991	0 2191	4 564
8	2 476	0 4039	12 300	0 0813	0 2013	4 968
9	2 773	0 3606	14 780	0 0677	0 1877	5 328
10	3 106	0 3220	17 550	0 0570	0 1770	5 650
11	3 479	0 2875	20 660	0 0484	0 1684	5 938
12	3 896	0 2567	24 130	0 0414	0 1614	6 194
13	4 363	0 2292	28 030	0 0357	0 1557	6 424
14	4 887	0 2046	32 400	0 0309	0 1509	6 628
15	5 474	0 1827	37 280	0 0269	0 1469	6 811
16	6 130	0 1631	42 750	0 0234	0 1434	6 974
17	6 866	0 1456	48 880	0 0205	0 1405	7 120
18	7 690	0 1300	55 750	0 0179	0 1379	7 250
19	8 613	0 1161	63 440	0 0158	0 1358	7 366
20	9 646	0 1037	72 050	0 0139	0 1339	7 469
21	10 800	0 0926	81 700	0 0122	0 1322	7 562
22	12 100	0 0826	92 500	0 0108	0 1308	7 645
23	13 550	0 0738	104 600	0 0096	0 1296	7 718
24	15 180	0 0659	118 200	0 0085	0 1285	7 784
25	17 000	0 0588	133 200	0 0075	0 1275	7 843

Table 7 0-T_3
12% Interest rate

15% INTEREST RATE

Year	A SCA	B SPV	C UCA	D USF	E UCR	F UPV
1	1 150	0 8696	1 000	1 0000	1 1500	0 870
2	1 322	0 7561	2 150	0 4651	0 6151	1 626
3	1 521	0 6575	3 472	0 2880	0 4380	2 283
4	1 749	0 5718	4 993	0 2003	0 3503	2 855
5	2 011	0 4972	6 742	0 1483	0 2983	3 352
6	2 313	0 4323	8 754	0 1142	0 2642	3 784
7	2 660	0 3759	11 070	0 0904	0 2404	4 160
8	3 059	0 3269	13 730	0 0729	0 2229	4 487
9	3 518	0 2843	16 790	0 0596	0 2096	4 772
10	4 046	0 2472	20 300	0 0493	0 1993	5 019
11	4 652	0 2149	24 350	0 0411	0 1911	5 234
12	5 350	0 1869	29 000	0 0345	0 1845	5 421
13	6 153	0 1625	34 350	0 0291	0 1791	5 583
14	7 076	0 1413	40 150	0 0247	0 1747	5 724
15	8 137	0 1229	47 580	0 0210	0 1710	5 847
16	9 358	0 1069	55 720	0 0180	0 1680	5 954
17	10 760	0 0929	65 080	0 0154	0 1654	6 047
18	12 380	0 0808	75 840	0 0132	0 1632	6 128
19	14 230	0 0703	88 210	0 0113	0 1613	6 198
20	16 370	0 0611	102 400	0 0098	0 1598	6 259
21	18 820	0 0531	118 800	0 0084	0 1584	6 312
22	21 650	0 0462	137 600	0 0073	0 1573	6 359
23	24 890	0 0402	159 300	0 0063	0 1563	6 399
24	28 630	0 0349	184 200	0 0054	0 1554	6 434
25	32 920	0 0304	212 800	0 0047	0 1547	6 464

Table 7 0-T_4
15% Interest rate

ESCALATION RATE										
Year	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	0 9182	0 9273	0 9364	0 9455	0 9546	0 9636	0 9727	0 9818	0 9909	1 0000
2	0 8430	0 8598	0 8767	0 8938	0 9111	0 9285	0 9461	0 9639	0 9818	1 0000
3	0 7741	0 7973	0 8209	0 8451	0 8697	0 8948	0 9203	0 9464	0 9729	1 0000
4	0 7107	0 7393	0 7687	0 7990	0 8302	0 8623	0 8953	0 9292	0 9641	1 0000
5	0 6526	0 6855	0 7198	0 7554	0 7925	0 8309	0 8709	0 9123	0 9553	1 0000
6	0 5992	0 6357	0 6741	0 7143	0 7565	0 8007	0 8471	0 8958	0 9467	1 0000
7	0 5502	0 5895	0 6312	0 6753	0 7221	0 7716	0 8241	0 8795	0 9381	1 0000
8	0 5041	0 5466	0 5910	0 6385	0 6893	0 7435	0 8015	0 8634	0 9295	1 0000
9	0 4638	0 5068	0 5534	0 6036	0 6579	0 7165	0 7797	0 8478	0 9211	1 0000
10	0 4258	0 4699	0 5181	0 5706	0 6279	0 6904	0 7584	0 8323	0 9126	1 0000
11	0 3911	0 4358	0 4852	0 5396	0 5995	0 6654	0 7378	0 8172	0 9044	1 0000
12	0 3591	0 4042	0 4544	0 5102	0 5724	0 6413	0 7178	0 8026	0 8964	1 0000
13	0 3297	0 3748	0 4254	0 4824	0 5463	0 6179	0 6981	0 7879	0 8882	1 0000
14	0 3027	0 3474	0 3983	0 4560	0 5213	0 5953	0 6789	0 7734	0 8799	1 0000
15	0 2779	0 3222	0 3730	0 4311	0 4977	0 5737	0 6605	0 7594	0 8720	1 0000
16	0 2552	0 2987	0 3492	0 4076	0 4750	0 5528	0 6424	0 7455	0 8639	1 0000
17	0 2344	0 2771	0 3271	0 3855	0 4536	0 5329	0 6251	0 7322	0 8564	1 0000
18	0 2151	0 2568	0 3061	0 3642	0 4327	0 5132	0 6077	0 7185	0 8481	1 0000
19	0 1975	0 2382	0 2867	0 3445	0 4132	0 4947	0 5913	0 7056	0 8407	1 0000
20	0 1813	0 2208	0 2684	0 3256	0 3943	0 4766	0 5750	0 6926	0 8328	1 0000
21	0 1665	0 2048	0 2513	0 3079	0 3764	0 4593	0 5594	0 6801	0 8253	1 0000
22	0 1530	0 1900	0 2355	0 2913	0 3595	0 4429	0 5445	0 6681	0 8183	1 0000
23	0 1404	0 1761	0 2205	0 2753	0 3431	0 4267	0 5295	0 6558	0 8107	1 0000
24	0 1289	0 1633	0 2063	0 2602	0 3273	0 4110	0 5148	0 6436	0 8030	1 0000
25	0 1184	0 1514	0 1933	0 2461	0 3126	0 3961	0 5009	0 6321	0 7959	1 0000

Table 7 0-T_5
SPF – Single payment factor - 10% Interest

ESCALATION RATE										
Year	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	0 9182	0 9273	0 9364	0 9455	0 9546	0 9636	0 9727	0 9818	0 9909	1 0000
2	1 7612	1 7871	1 8132	1 8393	1 8657	1 8921	1 9188	1 9457	1 9727	2 0000
3	2 5353	2 5844	2 6340	2 6844	2 7354	2 7869	2 8391	2 8921	2 9456	3 0000
4	3 2460	3 3237	3 4027	3 4834	3 5656	3 6492	3 7344	3 8213	3 9097	4 0000
5	3 8986	4 0092	4 1225	4 2388	4 3581	4 4801	4 6053	4 7336	4 8650	5 0000
6	4 4978	4 6449	4 7966	4 9531	5 1146	5 2808	5 4524	5 6294	5 8117	6 0000
7	5 0480	5 2344	5 4278	5 6284	5 8367	6 0524	6 2765	6 5089	6 7498	7 0000
8	5 5521	5 7810	6 0188	6 2669	6 5260	6 7959	7 0780	7 3723	7 6793	8 0000
9	6 0159	6 2878	6 5722	6 8705	7 1839	7 5124	7 8577	8 2201	8 6004	9 0000
10	6 4417	6 7577	7 0903	7 4411	7 8118	8 2028	8 6161	9 0524	9 5130	10 0000
11	6 8328	7 1935	7 5755	7 9807	8 4113	8 8682	9 3539	9 8696	10 4174	11 0000
12	7 1919	7 5977	8 0299	8 4909	8 9837	9 5095	10 0717	10 6722	11 3138	12 0000
13	7 5216	7 9725	8 4553	8 9733	9 5300	10,1274	10 7698	11 4601	12 2020	13 0000
14	7 8243	8 3199	8 8536	9 4293	10 0513	10 7227	11 4487	12 2335	13 0819	14 0000
15	8 1022	8 6421	9 2266	9 8604	10 5490	11 2964	12 1092	12 9929	13 9539	15 0000
16	8 3574	8 9408	9 5758	10 2680	11 0240	11 8492	12 7516	13 7384	14 8178	16 0000
17	8 5918	9 2179	9 9029	10,6535	11 4776	12 3821	13 7367	14 4706	15 6742	17 0000
18	8 8069	9 4747	10 2090	11 0177	11 9103	12 8953	13 9844	15 1891	16 5223	18 0000
19	9 0044	9 7129	10 4957	11 3622	12 3235	13 3900	14 5757	15 8947	17 3630	19 0000
20	9 1857	9 9337	10 7641	11 6878	12 7178	13 8666	15 1507	16 5873	18 1958	20 0000
21	9 3512	10 1385	11 0154	11 9957	13 0942	14 3259	15 7101	17 2674	19 0211	21 0000
22	9 5042	10 3285	11 2509	12 2870	13 4537	14 7688	16 2546	17 9355	19 8394	22 0000
23	9 6446	10 5046	11 4714	12 5623	13 7968	15 1955	16 7841	18 5913	20 6501	23 0000
24	9 7735	10 6679	11 6777	12 8225	14 1241	15 6065	17 2989	19 2349	21 4531	24 0000
25	9 8919	10 8193	11 8710	13 0686	14 4367	16 0026	17 7998	19 8670	22 2490	25 0000

Table 7.0-T_6
CSPF—Cumulative single payment factors—10% interest.

7.1 Introduction to Life Cycle Costing

7.1.1 Overview

With cheap energy and favourable economic conditions features of the past, more attention is being focused on the long-term impact of increasing operating and energy costs An aware owner or designer realizes that these on-going costs can now represent 50% or more of the true total costs incurred during the economic life of a building and thus deserve as much attention as capital costs.

With on-going owning and operating costs competing with capital costs for the designer's attention and available funds, a consistent and equitable method of economic evaluation is required To this end, life cycle costing offers the designer the necessary tool to perform such evaluations The technique is totally flexible, crossing all lines of discipline and accounting for all cost elements of a building in all time frames during its economic life, from inception to final disposal. Stated in a simpler way, it provides the necessary mechanism for trade-offs between all cost elements of a building and its operation at any time during the building's life cycle

For full effect, life cycle costing should be used at a time when the impact on the long-term costs will be optimal, prior to finalizing decisions that may be irreversible Since the major decisions affecting long-term costs are made in the planning and design stages, it is at this time that maximum use should be made of the technique Once design is completed and construction initiated, even the best cost saving proposals cause delays and often return minimal long-term cost reductions

Figure 7.1.1-1 illustrates the impact of time and effort on potential life cycle cost reductions from conceptual planning of a facility to the end of its economic life It clearly indicates that a relatively small effort during the planning and design stages can return substantial dividends It should also be recognized that the application of LCC at any stage can provide benefits and this is particularly the case with retrofit options, where at times unusually high returns on investment may result

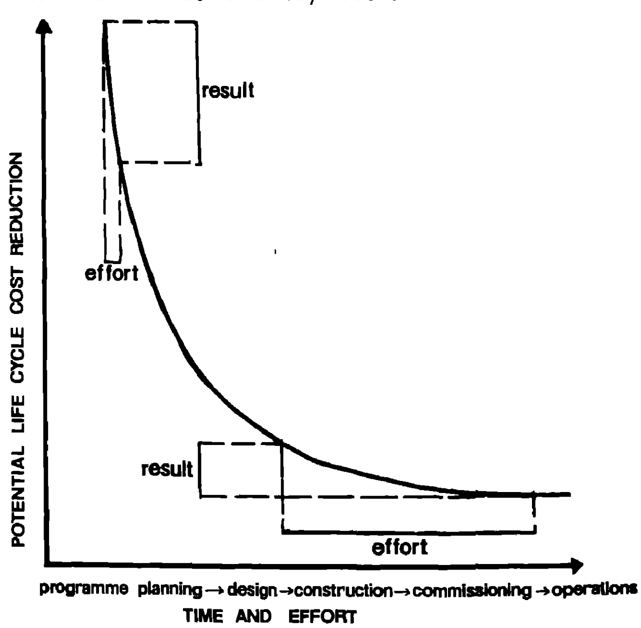

Figure 7.1.1-1
Impact of time and effort on life cycle costing

7.1 Introduction to Life Cycle Costing

7.1.2 Objectives

Life cycle costing provides visibility to all cost factors included in an analysis. Its broad objectives can be stated as follows
—to provide a clearly-defined methodical framework within which alternative solutions can be logically and fairly appraised
—to derive the optimum economic solution to facility design problems from all available alternatives
—to require design assumptions to be stated explicitly rather than intuitively
—to provide an analytical tool that can establish the interaction between planning and design decisions and long-term costs

7.1.3 Present Value Concept

It is essential that alternatives involving different magnitudes of capital costs and on-going operating, energy and maintenance expenditures must be brought together and appraised equitably so that funds can be allocated for maximum return. The capital costs are readily understood as these are usually displayed in present day dollars, but future costs are difficult to address due to the effects of time and inflation To resolve this problem, it is usual to employ the present value concept which transforms all future costs into present day values, while accounting for the effects of inflation and the value of money over time

Present value is defined as the amount of money in present day dollars that must be invested at a specific rate of interest to meet the required capital costs and owning and operating costs over the economic life of a project. For example, if an item costs \$100 00 today and remains at the same price for a year, the amount of money to be set aside now (present value – PV) at 10% interest to purchase this item in a year may be calculated as follows

$$PV \times 1\ 10 = \$100\ 00$$

$$PV = \frac{100}{1.10} = \$\ 90\ 91$$

If the cost of this same item were to escalate by 15% in a year, i.e cost \$115 00 at year end, then.

$$PV \times 1.10 = \$115\ 00$$

$$PV = \frac{115}{1.10} = \$104\ 55$$

Calculation techniques and tables for a wide range of economic conditions and financial evaluation approaches are discussed in greater detail in Section 7.4 of this chapter.

7.1.4 Energy Costs

Escalation rates for energy have not, in the past, differed considerably from the average inflation rate of the economy as a whole. This situation created little incentive or challenge for owners or designers to produce energy efficient buildings. In effect, energy in Canada has been traditionally inexpensive and was used accordingly.

The situation has changed dramatically during the past few years with the escalation rate for energy rising to equal or exceed bank

interest rates. The long-term outlook appears no more optimistic and, to illustrate the impact of escalating energy costs, present values are tabulated for an annual expenditure of $1 00 (expressed in today's dollars) at different rates of escalation, over a 20-year period at 10% interest:

Annual Escalation Rate	Present Value
0%	$ 8 51
5%	12.72
10%	20 00
15%	32 95

The present values shown are in effect the additional capital expenditure that would be justified to save $1 00/a at 10% interest over a 20-year period, i e they represent the amounts one could invest to break even in 20 years As can be readily appreciated from the figures, capital expenditure for energy savings based on 10%/a escalation would be more attractive than, say, capital expenditure for labour savings which may escalate at only 5%/a

Energy costs vary depending on the source and geographical location Actual costs must therefore be based on the specific fuel proposed For example, electrical energy in Alberta is in certain areas five times as costly as natural gas (2 5¢ vs 0 5¢ per equivalent kW h, whereas in Quebec, electrical energy is available at certain rate schedule brackets below the cost of natural gas or oil (0 8¢ vs 1 2¢ per equivalent kW h)

When several possible energy sources are being assessed, it is important that the projected escalation rate of each source be carefully considered, as a differential in escalation may well affect the end result of the analysis

7.1.5 Terminology

As in most technical areas, the terminology used in economic and financial evaluation varies widely Generally, the most current terms in use are employed in this chapter The term 'life cycle costing' is used extensively and can be taken to be synonymous with 'value engineering,' 'value management,' 'value analysis,' or with 'cost-benefit analysis'

d	— Depreciation period	m	— Mortgage rate percent
e	— Escalation rate, percent	n	— Year
i	— Interest rate, percent	t	— Tax rate, percent
B/C	— Benefit to cost rates	P	— Principal sum
CSPF	— Cumulative single payment factor	PV	— Present value
DX	— Depreciation expense	PX	— Principal expense
EUAC	— Equivalent uniform annual cost	SCA	— Single compound amount
FV	— Future value	SPF	— Single payment factor
LCC	— Life cycle costing	SPV	— Single present value
MA	— Mortgage amount	TPV	— Total present value
MP	— Mortgage payment	UCA	— Uniform compound amount
MPF	— Mortgage payment factor	UCR	— Uniform capital recovery
NCF	— Net cash flow	USF	— Uniform sinking fund
NPV	— Net present value	UPV	— Uniform present value

Table 7.1.5-T_1
Glossary of terms

7.2 Application of Life Cycle Costing

7.2.1 Introduction

Life cycle costing methods are applicable to all phases of the economic life of a facility, including retrofitting and renovations The approach requires that early consideration be given to the events occurring during the life cycle of a facility, from the planning stage to disposal and ensures that timely decisions can be made based on a fair appraisal of relative capital cost and long-term operating, energy and maintenance costs The procedure implies greater initial effort by designers, but the rewards of such an approach are substantial, as final documentation can be prepared with the assurance that all major decisions have been fully justified and documented

This section addresses the application of life cycle costing to the following phases during the life cycle of a facility

—Planning
—Conceptual design
—Design development
—Design documentation
—Procurement and construction
—Operations

7.2.2 Planning

Fundamental space delivery options, such as whether to build, renovate or lease, can be submitted to life cycle cost analysis, to determine the most cost effective option The long-term impact of escalating energy prices should be considered in each case, being equally applicable for the lease option as well as owner occupancy

7.2.3 Conceptual Design

This phase translates the program requirements into a building configuration taking account of all given constraints and the client's needs Ideally, several alternatives should be developed and life cycle costs calculated, in order to assist in selecting the most cost-effective concept for further design development

Energy considerations will rank highly in the analysis, particularly in the following areas

—configuration
—physical location
—orientation
—fenestration
—location of garages-above grade with no ventilation or underground
—construction above and/or below ground
—high-rise or low-rise construction

7.2.4 Design Development

With a cost effective configuration selected, the next stage of design will involve the selection of the basic building systems and the resolution of their inter-relationships Again, it is desirable to select for each major system a range of suitable alternatives to meet the criteria established and to subject each to life cycle cost analysis, individually and in acceptable combinations, in order to support selection decisions. A multi-disciplinary approach is essential at this stage, particularly in relation to the development of an energy efficient enclosure system and the related HVAC and electrical systems

7.2.5
Design Documentation

During the preparation of working drawings and specifications, final material and component selections will be made and final design details developed It may be desirable to conduct life cycle cost analyses to support these selections, but the major activity is ensuring that the decisions reached in previous phases are carried through into the final documentation

7.2.6
Procurement and Construction

During this stage, designers should be open to evaluating realistic proposals from contractors for cost reductions and alternates Again, it may be necessary to subject these alternates to life cycle cost analysis to assess their overall long-term economy

7.2.7
Operations

It is recommended that designers obtain feedback during facility operation, to provide realistic performance, statistical and cost data that may support the analyses conducted during design and also provide real data for input to future studies on other projects

Inevitably, as buildings age and the operations within them change, the necessity for replacements, renovations and alterations becomes evident Retrofitting existing buildings to optimize energy consumption is a continuing concern and life cycle costing may be applied to assessing alternative approaches and to justify the economic benefits of proposed investments

7.3 Methodology for Life Cycle Costing

7.3.1 Seven Necessary Steps

Life cycle cost analysis is a procedure by which a very complex task is accomplished in an orderly systematic manner Once the basic skills are developed to cope with the simpler problems, the same approach allows the larger complex problems to be dealt with effectively and with confidence This section identifies and explains seven necessary steps in the life cycle costing procedure, from the identification of objectives to the selection of design alternatives

7.3.1.1 Identification of Objectives (Step 1)

The objectives of the analysis should be clearly established at the outset, to ensure that the scope of work is delineated realistically to meet the objectives and no more.

Some of the objectives that can be met with life cycle costing procedures are as follows

—to evaluate the economics of competing design alternatives for elements of a building, e g use of triple glazing vs the use of double glazing

—to evaluate competing solutions that are sufficiently different to require all pertinent cost data for each solution to be analyzed, e g to renovate, lease, or build

—to evaluate the economic implications of an existing situation, e g to establish the true value of an income producing property based on annual long-term operating and maintenance costs

—to optimize the selection of a building element or component, e g to optimize wall insulation thickness or the mass of an exterior wall

—to assess the economic desirability of additional investments designed to produce future savings.

7.3.1.2 Selection of Financial Criteria (Step 2)

Having established the purpose and objective of the study, the next step is to select the interest and escalation rate or rates based on the best information currently available or to suit the client's own criteria The matter of dealing with the uncertainties in the selection of interest and escalation rates is dealt with later in **Section 7.5**

Current foreseeable interest and escalation rates in Canada for 1979 are as follows

Interest Rates	9% to 13%
Material escalation	5% to 11%
Labour escalation	6% to 10%
Energy escalation	9% to 14%

7.3.1.3 Developing Design Alternatives (Step 3)

Several design options should now be developed and defined Because life cycle costing provides the framework for the analysis of trade-offs between all capital cost elements and all operating and maintenance costs, seemingly radical solutions or alternatives should not be discounted off hand, even if they appear to fall outside the established energy, financial or performance constraints. For example, larger window areas usually mean higher heat losses and increased energy consumption, an apparent possible violation of an established energy budget. However, larger windows introduce more

light, which may reduce electrical consumption and possibly compensate for the additional heat loss

To compare alternatives equitably, a baseline alternative (which may be the 'do nothing' option) is defined against which all other alternatives will be compared This baseline alternative will usually meet minimum requirements dictated by the building codes, environmental criteria, safety considerations and performance

At this point, it may be wise to carry out a preliminary 'screening' of the options identified, before proceeding to the next step, with the object of eliminating those that are impractical or which will obviously result in substantially higher life cycle costs than the baseline case

7.3.1.4 Identification of Cost Factors (Step 4)

The costs admitted into the analysis will fall into one of the following categories capital costs, owning and operating costs, revenues, user costs and residual values

1 **Capital Costs** These are the costs associated with the development of a facility, and include construction, interim financing, site acquisition, design and management

2 **Owning and Operating Costs**: Included in this category are the following

—Operating and maintenance costs
Day-to-day operating and maintenance costs, which may include interest and mortgage payments, property and corporate taxes, insurances, equipment leases, security, administration, fuel, janitorial services, operating labour, service contracts, consulting and legal fees and allowances for depreciation

—Cyclical renewal costs
Intermittent cyclical renewals of worn, deteriorated or outdated components, including redecoration, minor repairs or replacement, alterations, etc

—Replacement and major repairs
Several major elements of a building will need to be replaced during its economic life, either due to deterioration, obsolescence or changes in operating conditions These costs are usually substantial and include such items as the replacement of the roof, window sashes, boilers, modernizing elevators, etc These costs are usually required to be capitalized and will be subject to depreciation, as opposed to being considered an operating expense and treated as a cash flow deduction during the year in which the work is done

.3 **Revenues** Revenues are to be treated as a cost, positive if there is a loss of revenue resulting from a decision, or negative if additional revenue results As an example, if the outside wall dimensions of a building are fixed, added insulation thickness may affect the net rentable floor areas and thus the revenue Similarly, the space occupied by a mechanical system also affects net rentable area and thus the revenues

.4 **User Costs:** These costs are associated with the activities of the building occupants as well as any process activities The efficiency of these activities may be affected by the environmental conditions or choice of systems. However, measuring the efficiency variations in such cases is a difficult task and, as a consequence,

these costs are often ignored when they are not considered a major issue User costs vary considerably in magnitude, for example, the life cycle cost of user activities in a hospital far exceeds the building and operational costs The opposite may be the case for an unattended warehouse where user costs would have an insignificant impact on total life cycle cost

.5 Residual Value: The residual or salvage value should be established for any cost element at the end of the life cycle of the study or when it is being replaced during the life cycle In this case, the cost of removal and disposal associated with replacement should be taken into account

When an element is expected to last for the normal life of a building, its terminal value in most cases can safely be assumed to be zero, because the calculated present value would normally be negligible

7.3.1.5 Selection of Time Periods (Step 5)

The analyst must determine the baseline year and also the time period or life cycle for the analysis. During this life cycle, it will be necessary to identify when components will be replaced (service life), when major overhauls need to be performed and to generally assign a point in time for every cost admitted, including loans and mortgage payments

For purposes of analysis, the life cycle of a building is usually equated to its economic life, i e the period of time over which an investment would be considered useful. The physical life of a building normally exceeds its economic life due to functional obsolescence in most cases

7.3.1.6 Calculation of Present Values (Step 6)

Having established the financial criteria, the costs to be admitted in the analysis and the time frame for each cost factor, the analyst can now proceed to calculate the total present value of each alternative A detailed description of present value calculation methods and evaluation techniques follows in **Section 7.4**, but for present purposes a simple example will be presented. The method used is essentially a basic version of the 'flow method' to clearly expose the mechanics of the process In this four-step method, a matrix for costs over time is tabulated, net cash flows are calculated for each year, the present value for each annual cash flow is calculated, and finally these present values are summed to establish the total present value.

The calculations that follow are based on the following information related to one of several alternatives under consideration.

Financial Criteria

Interest rate —10%
Escalation rates —10% for energy
0% for maintenance (fixed price contract)
Time period —4 years

Costs to be Admitted

Capital cost —$1,000.00
Energy costs —$100.00 during the first year and escalating 10% a year
Maintenance costs—$100.00 per year during each year of a 4-year fixed price contract

Residual value —the manufacturer has agreed to purchase the item for $100 00 after 4 years

.1 **Time Schedule of Costs:** With the basic information provided, a matrix can be established of the single and annual payments The result is very clear visual presentation of the distribution of annual costs as they occur during the period of the study

Year	Capital Cost	Maintenance Cost	Energy Cost
0	1,000	—	—
1	—	100	100
2	—	100	110
3	—	100	121
4	(100)	100	133

.2 **Annual Net Cash Flows:** Annual costs are now summed for each year, i e the net cash flow (NCF) is calculated

Year	Capital Cost	Maintenance Cost	Energy Cost	NCF
0	1,000	—	—	1,000
1	—	100	100	200
2	—	100	110	210
3	—	100	121	221
4	(100)	100	133	133

.3 **Present Values of Annual Net Cash Flows:** Each annual net cash flow must be transferred to a present value, i e stated in terms of today's dollar, being the amount which, if invested today over the relevant time period and specified interest rate, would be equal to the NCF

To calculate the present values, annual net cash flows are multiplied by factors incorporating the time and interest parameters These factors are called present value factors, which are derived from a compound interest equation

The compound interest equation provides the future value (FV) of a principal sum (P) deposited over 'n' years at an interest rate 'i' and is equal to:

$$FV = P(1 + i)^n$$

The formula for each year is derived as follows

Year	Future Value (FV)
1	$P(1+i)$
2	$P(1+i)(1+i) = P(1+i)^2$
3	$P(1+i)^2(1+i) = P(1+i)^3$
4	$P(1+i)^3(1+i) = P(1+i)^4$
n	$P(1+i)^{n-1}(1+i) = P(1+i)^n$

$$\therefore FV = P(1+i)^n$$

The factor $(1 + i)^n$ is called the compound interest factor or single compound amount factor (SCA factor).

If as shown
$$FV = P(1 + i)^n$$
$$P = FV\frac{1}{(1 + i)^n}$$

This formula therefore determines the principal sum required to provide a future amount at an interest rate 'i' The factor $\frac{1}{(1 + 'i')^n}$ is termed the single present value factor and is the inverse of the single compound amount factor (SCA)

The single present value factors for the example may now be calculated as follows

Year	Single Present Value Factor
1	$\frac{1}{(1+0\ 10)^1} = 0\ 9091$
2	$\frac{1}{(1+0\ 10)^2} = 0\ 8264$
3	$\frac{1}{(1+0\ 10)^3} = 0.7513$
4	$\frac{1}{(1+0\ 10)^4} = 0.6830$

Present Values of each annual net cash flow may now be determined as follows

Year	NCF	PV Factor	PV
0	1,000	1.0000	1,000
1	200	0.9091	192
2	210	0.8264	165
3	221	0.7513	166
4	133	0.6830	91
Total	—	—	$1,614

.4 **Total Present Value:** The total present value is the sum of the annual present values, totalling in the example $1,614.00, i e this sum invested today at 10% interest would cover all capital and operating costs for the 4-year period. The present values of other alternatives may be higher or lower and a choice can only be made by evaluating the total present values, since the basic parameters such as the time period of the study may vary

7.3.1.7
Evaluation and Selection of Alternatives (Step 7)

Total present value as determined in the example is a suitable economic measurement to choose between competing alternatives with equal lives, the lowest total present value indicating the preferred choice. However, should the lives be unequal, it is logical to think of annualizing the total present values over the life cycle or time period for each alternative to arrive at uniform annual values, the lowest indicating the favoured alternative This approach is similar to a mortgage situation where uniform annual amounts are established to repay a principal sum or loan over a specified period of time.

Additional economic measurements are described later in this chapter to assist in presenting results to the decision-maker in clear, concise and useful terms Several of these techniques may be required for a particular analysis situation, depending on the complexity of the problem, the nature of the alternatives, and the requirements and priorities of the decision-maker

7.4 Financial Concepts

7.4.1 Approach

Understanding the financial concepts of life cycle costing and economic analysis need not be difficult Six essential considerations are set out below and then discussed in detail in this section. If read sequentially the following should provide a sound background in the subject

—Economic Parameters—interest, escalation and their interaction
—Time Value of Money—effect on money of the basic economic parameters and time factors.
—Present Value Calculations—structuring of cost data into a format suitable for evaluation.
—Mortgages Depreciation and Taxes—methods of handling
—Evaluation Techniques—selection of methods compatible with objectives of the analysis.
—Presentation—structuring of data and use of graphics to facilitate decision making

7.4.2 Economic Parameters

To determine the present value of future expenditures and revenues, it is necessary to define and quantify those factors that influence the change of the value of money over time, i.e. what the effects will be of interest and escalation rates in determining the present values of labour, materials, energy, mortgage re-payments, etc.

7.4.2.1 Interest Rates

Interest rates are particular to the investor and the degree of risk In economic analysis, interest rates may often be referred to as cost of capital, required rate of return, discount rate or opportunity rate.

The appropriate interest rate to employ in calculations is usually the rate at which the investor can borrow funds; in the private sector, this may be the rate on prime corporate bonds. If part of the capital is to be provided by the investor by way of equity funding, consideration must be given to the value of the internal rate of these funds, since they would no longer be available for other uses, usually at higher rates of return than for borrowed funds. Therefore, a combined rate may be calculated using the internal rate of return and the interest rate on borrowed funds It is appropriate if not essential that the cost of capital and other financial parameters be established at an early date with the client

7.4.2.2 Escalation Rates

Future prices can be expected to increase and this must be taken into account in any economic analysis. Escalation rates are particular to the cost item in question and can usually be expected to differ for each category. Certain items may have effectively no escalation as in the case of mortgage re-payments as these are payments pre-set at a constant amount

7.4.2.3 The Real Rates of Interest

The real rate of interest is a measure of the relationship between escalation and interest rates Nominal interest rates on the average are generally greater than escalation over the long run, allowing the investor to earn an amount that compensates for escalation (inflation), plus an extra amount, which is termed the 'real rate of return.' Historically, real interest rates are in the 2% to 5% range and ultimately correspond to the rates of national economic growth Instead of noting actual escalation rates in present value calculations, the real rate of interest may be used These values are calculated as follows based on a principal amount of one dollar and a period of one year

—value of \$1 after a one-year period at nominal interest = $1 + i$

—escalated value of \$1 after a one-year period = $1 + e$

—real value of \$1 after a one-year period = $\frac{1+i}{1+e} = 1 + R$,

where R is termed the real rate of interest

$$\therefore R = \frac{1+i}{1+e} - 1$$

As an example, if one invests \$100 00 now at $i = 10\%$ to pay for something costing \$100 00 now but escalating at a rate $e = 8\%$, in a year's time one will have \$110 00 to buy the item that will cost \$108 00 The difference of \$2 represents the real amount earned and since the real rate of return must be based on the escalated value of the item, i e, \$108 00, it is equal to the following

$$R = \frac{2}{108} = 1\ 85\%$$

$$\text{or } R = \frac{1+i}{1+e} - 1 = \frac{1+0\ 10}{1+0\ 08} - 1 = 1\ 0185 - 1 = 0\ 0185 = 1\ 85\%$$

As an approximation, however, the difference between the interest rate and the escalation rate (termed the spread) may be assumed equal to the real rate of interest, i e

$$S(\text{spread}) = i - e = 10\% - 8\% = 2\%$$

Real rates of interest covering a limited horizon of, say, ten years may be expected to vary approximately as follows

Labour	0% to +4%
Materials	−1% to +5%
Energy	−4% to +1%

These are based on a 10% interest rate

Note that negative real rates imply escalation rates higher than anticipated interest rates

7.4.2.4 Variations in Parameters

The life cycle costing practitioner must confront two real problems in order to ensure that a final decision can be taken with assurance These are:

—genuine uncertainties in the forecast of interest or escalation rates

—the outlook of decision makers, be they optimists, pessimists or somewhere in between.

To overcome these problems, one option is to adopt pessimistic, median and optimistic scenarios, using variations in the real rate of interest to determine the sensitivity of life cycle costs to these parameters Low or negative real rates denote pessimism, i e escalation is close to or exceeds the interest rate as may be the case for energy, high real rates of interest denote economic optimism, i e with escalation much lower than interest rates, as in a stable market with little inflation.

To judge the effect of possible variations in escalation rates, a set of economic parameters can be established reflecting these three different expectations In the case of energy costs, average escalation rates of 10% are presently quoted with the optimists claiming this should be lower and pessimists claiming this should be much higher The following table represents different scenarios that express anticipated fluctuations in the rate for 8%, 11% and 14% escalation

Scenario	Interest Rate	Escalation Rate	Spread	Real Rate
Optimistic	10%	8%	2%	1 85%
Median	10%	11%	−1%	−0 90%
Pessimistic	10%	14%	−4%	−4.51%

If a proposed alternative delivers the best value under all three conditions, it is very likely that it should be undertaken, if it can only be justified in the first situation, it is necessary to consider how optimistic one can be about the future of energy costs.

Analyzing the effect of variations in economic parameters is termed sensitivity analysis and is addressed in Sections 7.5 and 7.6 of this chapter.

ue of Money

The life cycle costing analyst must deal with a complex maze of numbers that in themselves may be subject to variations and attempt to establish some order for a rational analysis to support a decision or recommendation. The costs admitted include future costs which may be annual, non-recurring or cyclical in nature, all of which may be subject to differing escalation rates that cannot be established with certainty. In addition, the time frame or expected life for various elements may vary, thus adding to the complexity of the problem

The skill of the analyst lies in his ability to manipulate these costs through time with the appropriate variations in the basic parameters of interest and escalation, i.e all costs are related to present day values, or to a future value, or to equivalent annual values. To this end, the interaction of interest, escalation and time on money must be well understood.

7.4 Financial Concepts

The time value of money is based on the mathematics of compound interest for which the basic equation has been presented earlier Calculations for energy evaluations are usually based on one-year periods, for the sake of simplicity

The equations required to carry out the manipulation of money values are set out in **Table 7.4.3-T_1**, which includes an explanation of each technique, a reference to financial tables or graphs in this chapter where factors may be obtained and a simple example No attempt has been made to derive the equations as this information is readily available from economic or engineering texts. Most of the tables presented are based on a 10% interest rate, which is reasonably close to the current rate of interest.

There are two factors for which both interest and escalation are variables, i.e. the SPF and CSPF factors Tables are presented for these factors based on a 10% interest rate and escalation rates varying from 1% to 10%

Equations are presented in **Table 7.4.3-T_1** to cover the following situations:

Effect of interest on a principal sum

—to determine the future value of a principal sum (SCA)

—to determine the present value of a future principal sum (SPV)

Effect of escalation on a single cost

—to determine the future value of base year cost (year 0) escalating at a constant annual rate 'e' (SCA)

Effect of escalation and interest on a single cost

—to determine the present value of a base year cost (year 0) escalating at a constant annual rate 'e', at an interest rate 'i' (SPF).

Effect of interest on annual uniform amounts

—to determine the future value of a series of uniform annual amounts (UCA)

—to determine the present value of a series of uniform annual amounts (UPV).

Effect of escalation and interest on annual escalating amounts

—to determine the present value of a series of amounts increasing at a constant escalation rate 'e', at an interest rate 'i' (CSPF)

—to determine the future value of a series of annual amounts increasing at a constant escalation rate 'e', at an interest rate 'i'

Effect of interest on converting principal sums to equivalent annual values

—to determine the uniform annual payment required to repay a principal sum (UCR).

—to determine the uniform annual amount required to produce a future principal sum (USF)

An understanding of the formulae will greatly assist the analyst in understanding the evaluation techniques that follow

7.4 Financial Concepts

TABLE OF TIME VALUE OF MONEY FACTORS				
Item	Purpose	Factor	Equation	Example
1	To determine the future value of a principal sum at an interest rate 'i'	SCA Single Compound Amount (see Tables 7 0-T_1 to T_4, Col A)	$FV = P(1+i)^n$ $= P \times SCA$	The future value of \$1,000 00 in 10 years at 10% interest FV = P × SCA = 1000 × 2 594 = \$2,594 00
2	To determine the present value of a future principal sum or cost at an interest rate 'i'	SPV Single Present Value (see Tables 7 0-T_1 to T_4, Col B)	$PV = FV \times \frac{1}{(1+i)^n}$ $= FV \times SPV$	The present value of \$1,000 00 in 10 years time at an interest rate of 10% PV = P × SPV = 1000 × 0 3855 = \$385 50
3	To determine the future value of a one time base year cost escalating at a rate 'e'	SCA Single Compound Amount (see Tables 7 0-T_1 to T_4, Col A)	$FV = P(1+e)^n$ $= P \times SCA$	The future value of \$1,000 00 cost in 10 years at an escalation rate of 8% FV = P × SCA = 1000 × 2 16 = \$2,160 00
4	To determine the present value of a cost in year n, based on a given base year cost, escalating annually at an escalation rate e' and with interest rate 'i'	SPF Single Payment Factor (see Table 7 0-T_5) or Determine FV per #3, then PV per #2	$PV = P \times \left[\frac{1+e}{1+i}\right]^n$ $= P \times SPF$ If 'e' = 0, SPF = SPV (#2)	The present value of a \$1,000 00 cost in year 0 projected to 10 years at an escalation rate of 5% and 10% interest rate PV = P × SPF = 1000 × 0 6279 = \$627 90
5	To determine the future value of a series of uniform annual amounts at an interest rate 'i'	UCA Uniform Compound Amount (see Tables 7 0-T_1 to T_4, Col C)	$FV = A \frac{(1+i)^n - 1}{i}$ $= A \times UCA$	The future value of \$1,000 00 deposited annually for 10 years at 10% interest FV = A × UCA = 1000 × 15 94 = \$15,940 00
6	To determine the present value of a series of uniform annual amounts at an interest rate 'i'	UPV Uniform Present Value (see Tables 7 0-T_1 to T_4, Col F Figure 7 4 3-1)	$PV = A \times \frac{(1+i)^n - 1}{(1+i)}$ $= A \times UPV$	The present value of \$1,000 00 deposited annually for 10 years at 10% interest PV = A × UPV = 1000 × 6 144 = \$6,144 00
7	To determine the present value of a series of uniform annual amounts increasing at an escalation rate 'e' and with interest rate 'i'	CSPF Cumulative Single Payment Factor (see Table 7 0-T_6 and Figure 7 0-1 at end of Section 7 0 also Figure 7 4 3-1)	$PV = A \times \frac{1 - \left[\frac{1+e}{1+i}\right]^n}{\left[\frac{1+i}{1+e}\right]^n - 1}$ $= A \times CSPF$ Valid for $e \neq i$ If 'e = i', CSPF = 'n If 'e' = 0, CSPF = UPV (#6)	The present value of a \$1,000 00 annual energy saving (year '0') which is increasing or escalating by 8% each consecutive year for a 20 year period PV = A × CSPF = 1000 × 16 5873 = \$16,587 30
8	To determine the future value of a series of annual amounts increasing at a constant escalation rate 'e' and with interest rate 'i	(a) determine PV with CSPF factor per #7 (b) determine FV with SCA factor per #1		The future value of a \$1,000 00 annual energy saving (year 0') escalating at 8% each consecutive year for a 20 year period (a) PV = A × CSPF = 1000 × 16 5873 = \$16,587 30 (b) FV = PV × SCA = 16,587 30 × 6 727 = \$111,582 77
9	To determine the uniform annual amount required to repay a principal sum at interest rate 'i'	UCR Uniform Capital Recovery (see Tables 7 0-T_1 to T_4, Col E)	$A = P \times \frac{i(1+i)^n}{(1+i)^n - 1}$ $= P \times UCR$	The uniform annual amount to repay a sum of \$1 000 00 over a 10 year period, at 10% interest A = P × 0 1628 = \$162 80
10	To determine the uniform annual amount which at an annual interest 'i' will have a future value FV	USF Uniform Sinking Fund Factor (see Table 7 0-T_1 to T_4, Col D)	$A = FV \times \frac{i}{(1+i)^n - 1}$ $= FV \times USF$	The uniform annual amount which at 10% interest over 10 years will have a future value of \$1,000 00 A = FV × USF = 1000 × 0 0628 = \$62 80

Abbreviations—P —Principal sum   A —Annual amount
PV—Present value   FV—Future value

Table 7.4.3-T_1.
Equations for calculation of time value of money.

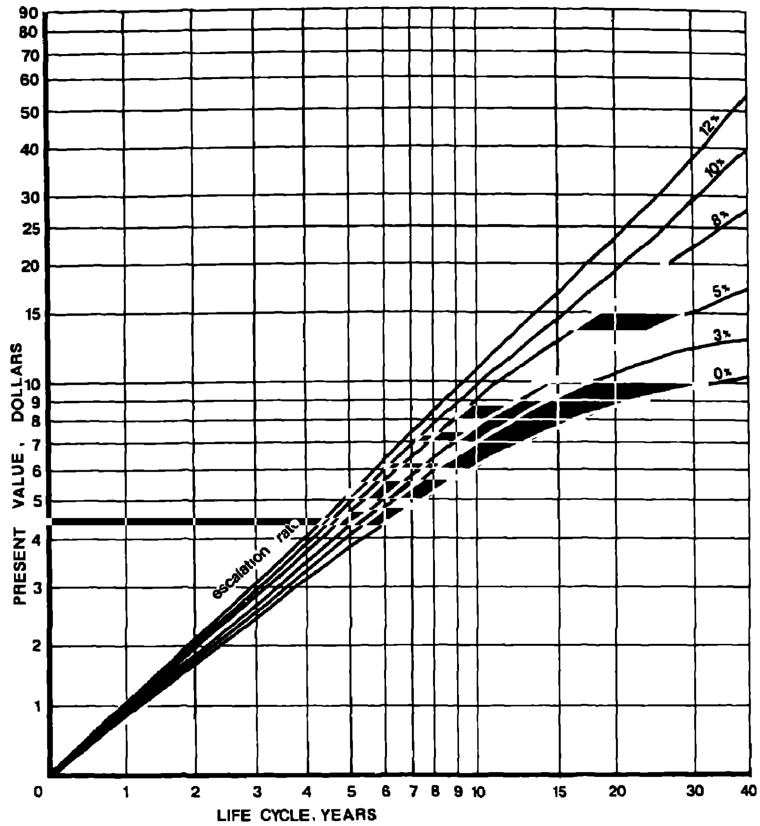

Figure 7 4 3-1
Time value of money

7.4.4 Present Value Calculation Techniques

Once the analyst has mastered the principles of the time value of money, calculations of present values may be prepared for alternatives utilizing one or several of the calculations or factors previously outlined The alternatives being analyzed will require that escalation and interest rates be established for each element, that costs be transposed within the time frame of the study period or its life cycle and that mortgage payments, depreciation and taxes be taken into account

In order to cope with these additional complexities, two basic techniques can be utilized, the formula method for the simpler cases and the flow method for the more complex ones

7.4.4.1 The Formula Method

In this method, all costs incurred during the period of analysis are converted to present values, i.e. costs in terms of today's dollar, using the equations previously outlined that account for interest, escalation and time characteristics The present values for all costs are then summed to produce the total present value, a relatively simple procedure if no taxes or mortgage payments are involved It is not necessary to determine annual cash flows, which can be a long process if it involves numerous cost categories over a large number of years with many alternatives

The equations and factors previously listed in Table 7.4.3-T_1 for calculating present values are as follows

Single Present Value Factor (SPV)
The present value of a future cost at an interest rate 'i'

Single Payment Factor (SPF)
The present value of a base year cost in year n escalating annually at a rate 'e' and with interest rate 'i'

Uniform Present Value Factor (UPV)
The present value of a series of annual amounts at an interest rate 'i'

Cumulative Single Payment Factor (CSPF)
The present value of a series of annual amounts increasing at a uniform escalation rate 'e' and with interest rate 'i'

Example:
The details of one of the alternatives being considered in a study are as follows

Capital investment	\$10,000
Interest rate ('i')	10%
Escalation ('e')	nil for maintenance 4% for materials 9% for energy
Time period	. 20 years
Annual maintenance.	\$400
Component replacement cost in 10 years	\$2,000 at current cost
Annual energy costs	\$500 at current cost
Residual value after 20 years . .	\$1,000 at current cost

To determine the Present Value of this alternative:

Present value of capital investment .	\$10,000 00
Present value of annual maintenance 400 × UPV = 400 × 8 514 (i = 10%, e = 0%, n = 20)	\$3,405 60
Present value of component replacement in 10 years 2000 × SPF = 2000 × 0 5706 (i = 10%, e = 4%, n = 10)	\$1,141 20
Present value of annual energy costs 500 × CSPF = 500 × 18 20 . (i = 10%, e = 9%, n = 20)	\$9,100 00
Present value of residual value 1000 × SPV = 1000 × 0 1486 (i = 10%, e = 4%, n = 20)	\$ 148 60
Total Present Value:	\$23,795 40

The formula method is an efficient time-saving procedure to determine present values, since the present value of each cost through any number of years is calculated directly for the base year and all values are summed. It does however have some drawbacks in that it cannot cope with the more complex situations, is not readily adaptable to some evaluation techniques, and the information resulting does not make visible the dynamic nature of the process on a year-to-year basis. It is however possible to use the formula method to calculate 5 year increments which can then illustrate the time dynamics involved.

7.4.4.2 The Flow Method

In the formula method, one calculation is made for each cost element identified to establish the aggregate present value, no attempt is made to examine the nature of each cost on a year-to-year basis, or all the costs for a particular year

As opposed to this procedure, the flow method exposes each cost element on a yearly basis, as well as the annual combined effect, thus making visible to the analyst the dynamic nature of the process and providing more information for analysis

In this method, cost elements for each year are tabulated to determine the net cash flow (NCF), each resulting annual net cash flow is converted to a present value, and all present values are summed to determine the total present value This method is basically utilized in **Section 7.3** of this chapter for the very simple examples presented.

When numerous calculations are involved due to a large number of alternatives or cash flow items to be considered over a long period of time, the process is tedious and the use of computer programs should be considered

To prepare for this procedure, a matrix is established with the years horizontally and cost items forming the columns The first year is year '0' for entry of initial cost items, and subsequent years are 1, 2, 3, 'n', for entry of other future owning expenditures, such as energy costs or major repair costs. These future costs are entered in terms of actual costs for that particular year because they will be discounted in the procedure To establish these future costs, calculations are made based on present day costs and the escalation and interest criteria developed for that particular item The costs for each year are summed to provide the net cash flow (NCF) for that particular year, each annual NCF is discounted to arrive at its present value, and the present values are summed to provide the total present value

In summary, where the year number is 'n', the interest rate is 'i', and escalation rates 'e' are established for each cost item, the procedure is as follows

- —Enter in the appropriate year all actual costs in terms of dollar value for that particular year In most cases, these costs will be determined from escalated base year costs or year '0' costs, i e year '0' costs $\times$ $(1+e)^n$ or year '0' costs $\times$ the appropriate single compound amount factor (SCA)
- —For each year, sum horizontally and obtain the annual nominal net cash flow (NCF).
- —For each year, calculate the present value by discounting the NCF, i e NCF $\div (1+i)^n$, or NCF $\times$ the appropriate single present value factor (SPV)
- —Sum annual present values cumulatively to obtain the total present values Cumulative values are of interest for purposes of analysis and graphical presentations.

The example used for the formula method is repeated for the flow method and is illustrated in **Table 7.4.4-T_1**.

PRESENT VALUE CALCULATION—FLOW METHOD								
	Costs and Revenues $					Net Cash Flow (NCF) F	Annual PV G	Total PV H
Year	Initial Invest-ment A	Energy Costs B	Main-tenance Costs C	Replace-ment Costs D	Residual Value E			
0	10,000					10,000	10 000	10,000
1		545	400			945	859	10,859
2		594	400			994	822	11,681
3		648	400			1,048	787	12,468
4		706	400			1,106	755	13,223
5		769	400			1,169	726	13,949
6		839	400			1,239	699	14,648
7		914	400			1,314	674	15,322
8		996	400			1,396	652	15,974
9		1,086	400			1,486	630	16,604
10		1,184	400	2,960		4,544	1,752	18,356
11		1,290	400			1,690	592	18,948
12		1,406	400			1,806	576	19 524
13		1,533	400			1 933	560	20,084
14		1,671	400			2 071	545	20,629
15		1,821	400			2,221	532	21,161
16		1,985	400			2,385	519	21,680
17		2,164	400			2,564	507	22 187
18		2,359	400			2,759	496	22,683
19		2,571	400			2,971	486	23,169
20		2,802	400		2,191	5,393	802	23,970

(B) $500 \times (1 + e)^n = 500 \times SCA$. 'e' = 9%. (C) Constant Value. (D) $2000 \times (1 + e)^n = 2000 \times SCA$. 'e' = 4% (E) $1000 \times (1 + e)^n = 1000 \times SCA$. 'e' = 4%. (F) A + B + C + D + E. (G) PV = F × SPV. 1 = 10%. (H) Cumulative totals of G

Table 7.4.4-T_1
Present value calculation—flow method

7.4.5 Mortgage Depreciation Payments, and Income Tax

The introduction of mortgage payments, depreciation and income taxes initially may appear to be very intricate; however, given an understanding of the cash flows generated, they can easily be managed with the basic concepts developed so far.

7.4.5.1 Mortgages

In private sector building, it is usual for a significant part of the initial cost to be financed through a mortgage loan, which results in cash flows for mortgage payments. If a mortgage amount 'MA' is borrowed, then the annual mortgage payment 'MP' will be:

$$MP = MA \times \frac{1}{UCR\ (m,p)}$$

where m = mortgage interest rate, and p = period over which the mortgage is to be repaid. For example, for a 10% mortgage to be repaid over 25 years, UCR (10%, 25) = 9.077; if $800,000 were borrowed (MA), annual payments would be $88,134 (MP). (The quotient of 1/UCR (m,p) is often referred to as the 'mortgage constant').

When income tax is involved, it is necessary to note that only the interest portion and not the principal repayment portion is claimable as a deduction to taxable income. We may write:

$$MP = IX(n) + PX(n)$$

where IX and PX are the interest and principal expense portion respectively in any year 'n' of the mortgage payment Then,

$$PX(n) = MA \quad (UCR(m,p) - m) \quad (1 + m)^{n-1}$$

and IX (n) = MP − PX(n), for any year 'n' (How this may be used will be illustrated in the section on income taxes following)

7.4.5.2 Depreciation

Accounting depreciation is a 'book' or 'paper' expense, and does not give rise to any actual operational cash flow Depreciation expense allowances however are claimable as deductions for tax purposes In Canada, this takes the form of capital cost allowances, whereby a certain percentage of an item's capital cost is claimable on a declining balance basis. For example, an item with a capital cost of $2,000, may have a capital cost allowance rate of 5% in the first year, $100 is claimable (5% of $2,000), in the second year, $95 is claimable (5% of $1,900, the declined balance) Generally, the depreciation expense, DX, in any year 'n', equals

$$DX = C[a(1 - a)^{n-1}]$$

where 'C' is the capital cost and 'a' is the capital cost allowance rate Usually, anything attached to a building bears a capital cost allowance rate equal to that of the whole building, which in most cases equals 5% Certain semi-permanent equipment however may bear higher rates. In such cases, it is advisable to check with the client's tax accountant

7.4.5.3 Income Tax

To calculate income tax, it is first necessary to find TI, taxable income This equals net cash flow, NCF, adjusted for mortgages and depreciation As NCF would already include mortgage payments, both principal and interest, as deductions, it is necessary only to add-back PX, principal expense, and to deduct DX, depreciation expense

$$TI = NCF + PX - DX$$

Where 't' is the marginal tax rate, the amount of tax is $t \times TI$, and the net after tax cash flow, NATCF, is

$$\begin{aligned} NATCF &= NCF - t(NCF + PX - DX) \\ &= (1 - t)NCF + t(DX - PX) \end{aligned}$$

A calculation example involving income tax appears in Section 7.5.

7.4.6 Present Value Evaluation Techniques

Previous sections have dealt with the techniques and issues income. This equals net cash flow, NCF, adjusted for mortgages frame, to arrive at a single lump sum value for all components admitted into the analysis.

It is now necessary to examine alternative ways in which these values may be used to arrive at decisions on the alternative that presents the best economic choice. At times, decisions may be made

on a simple evaluation of present value totals for each alternate, but more often decision makers may be interested in having answers to one or more of the following questions:

—how to evaluate two or more alternatives with equal or unequal lives
—what point in time will an investment or an extra investment be re-paid
—at what point in time will the net present value of an alternative with higher initial capital investment become less than another alternative with a lower investment
—what are the savings/investment ratios of each alternative
—what factors provide an indication of minimum risk
—what is the value of an unknown factor that will result in a break-even situation with other factors established.

Several methods of presenting and evaluating the financial calculations follow.

7.4.6.1 Total Present Value (TPV)

Where all cost factors of alternatives are considered and lives are equal, the lowest resulting TPV of an alternative will be the preferred choice

7.4.6.2 Net Present Value (NPV)

Where life can be fairly-well estimated, the NPV always indicates the favoured alternative. The NPV is the TPV of an alternative less the TPV of the 'do-nothing' alternative, provided PV's are calculated with equal lives The highest positive NPV is the decision criterion, a negative NPV indicates the do-nothing alternative is superior. It is possible to calculate NPV's directly, using differential cash flows which eliminates the need to calculate the TPV of the baseline case

7.4.6.3 Equivalent Uniform Annual Cost (EUAC)

The EUAC is an annualized form of the present value.

EUAC = Total Present Value × UCR (Uniform Capital Recovery)

The EUAC must be used for comparing alternatives with unequal lives as the difference in lives is accounted for bv the UCR factor It is particularly useful for budgeting or planning studies

7.4.6.4 Simple Payback

When capital investment and annual cost savings can be readily established, simple payback is the least complex form of economic measurement In its simplest form, the initial investment is divided by the annual cost saving to arrive at the payback period.

However, the approach is not reliable as a measure of overall economic performance because it ignores the time value of money. Further, payback analysis fails to present a fair evaluation of alternatives with different physical lives

Because of its simplicity, however, it can be used by everyone and is a useful tool for a preliminary evaluation of alternatives. When, however, an investment is to be made and a minimum true payback is specified, it is convenient to determine the equivalent simple

payback period to avoid numerous calculations and establish guidelines that can be readily used by everyone A graphic method relating simple payback to true payback is presented and a description of the latter method follows.

7.4.6.5 True Payback Period (Discounted Payback Period)

When a running cumulative annual NPV is calculated, the year in which the NPV changes from negative to positive is the true payback period, i e. the point at which the initial investment is re-paid in full from future after-tax revenues generated, including the interest on the investment during this period This measure is most readily obtained from the flow method of calculation, but can also be obtained with the formula method by calculating NPV's at different intervals and interpolating the results The least risk situation is identified by the shortest payback period, before the expiry of anticipated physical life This method is not a substitute for NPV, but provides additional information for decision making

The relationship between true payback and simple payback periods can readily be determined graphically as follows·

—When e=0 and the interest rate is 10%, given one parameter, the other can readily be determined from **Figure** 7.4.6-1. Other curves could be drawn for differing rates of interest.

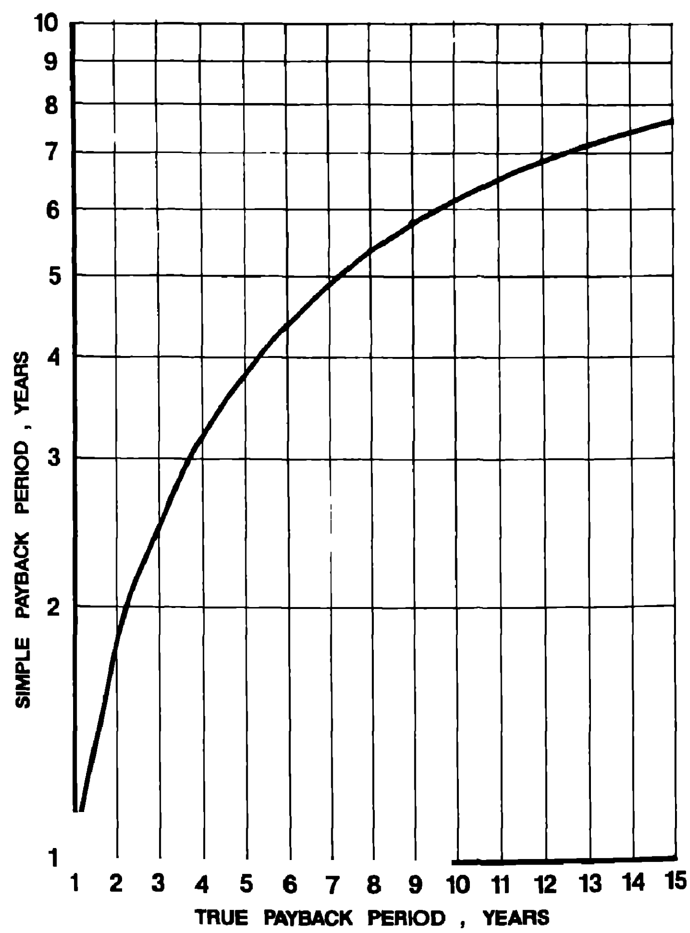

Figure 7.4.6-1
Graph of true payback vs simple payback period at 10% interest.

—When 'e' is not equal to 0 the real rate of interest R is calculated as outlined in Section 7.4 2.3 and the relationship between simple payback and true payback is determined from the curves in Figure 7.4.6-2

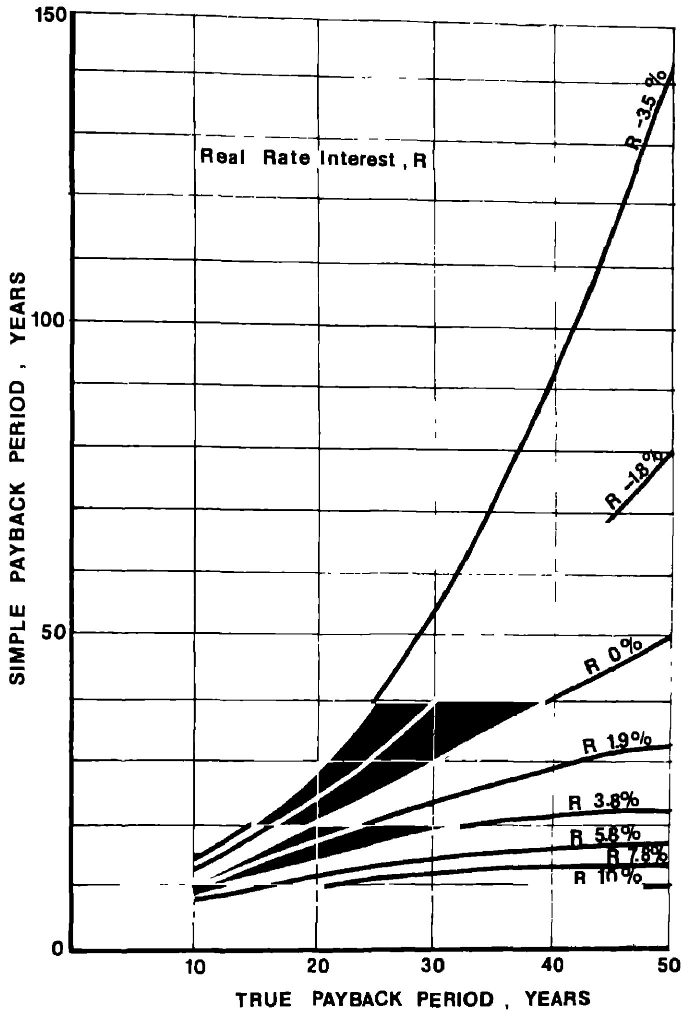

Figure 7 4 6-2
Graph of true payback period vs simple payback period based on real rate of interest

7.4.6.6 Benefit/Cost Ratio (Savings/Investment Ratio)

When present values of benefits or savings are calculated over the life of an alternative, they should exceed the initial investment required to produce these benefits, in order for the investment to be cost effective. The greater the savings for the same investment, the greater becomes the ratio of savings to investment and the greater the cost effectiveness.

For this method, present values of benefits or savings are calculated separately and the quotient of present value savings/investment is termed the savings investment ratio or the benefit cost ratio

This method of analysis is particularly effective when the time period or initial capital investment differences amongst alternatives is significant It is also useful in the selection of a preferred investment when the net present values are nearly equal, because the higher benefit/cost ratio indicates a greater rate of return, and a quicker payback combined with reduced risk The benefit/cost ratio (B/C) can be calculated as

$$B/C = \frac{\text{NPV} - \text{Initial Investment}}{\text{Initial Investment}}$$

7.4.6.7 Cross-Over Point

When two alternatives are compared and one alternative has the highest initial investment and the lowest net present value, it is of interest to know the year in which the NPV of one becomes and remains greater than the other, i e , the cross-over point If this point in time is close to the time period of the study, the greater risk and uncertainties may favour a lesser investment but with a higher NPV if, on the other hand, the cross-over point occurs within a reasonable number of years in relationship to the life cycle period, the investor will tend to favour this situation because of reduced risk associated with the shorter time period

The determination of the cross-over point can readily be achieved by plotting several points for the calculated NPV's vs time for each alternative and drawing the intersection of the curves This can also be accomplished by plotting running TPV's over time

7.4.6.8 Break-Even Analysis

As the name suggests, break-even analysis is the determination of the conditions under which an investor can recuperate an investment when one of the factors is unknown and must be determined, e g initial investment, minimum life (time payback period), or annual benefits or savings

The investment is recovered when the NPV curve changes from negative to positive, i e when the NPV is '0' The value of the unknown factor may therefore be solved by equating the NPV to '0' and inputting the two known values to determine the third and unknown value

For example, if the possibility of installing thermal shutters in a building is considered, the initial capital investment and the time frame for the study are known, with the annual savings necessary to justify the investment to be determined by break-even analysis

The approach can also be utilized to determine the level of increased activity or efficiency required to justify a capital expense, e g if humidification or air conditioning is considered likely to improve the working environment, the resulting increase in productivity to justify the investment can be determined.

7.4.6.9 Rates of Return

Rates of return are sometimes used for economic measurement As they can be widely misinterpreted and as some are difficult to calculate, only the basic definitions are presented here

—Simple Rate of Return = $\dfrac{\text{Annual Saving}}{\text{Initial Investment}}$

This formula ignores escalation, is difficult to apply to several cash flows and is not applicable where terminal values need to be considered

—Internal Rate of Return = the value of 'i' at which the NPV = 0

This measure is used widely by industry, but is difficult to calculate and to interpret

—True Rate of Return = $\sqrt[n]{\dfrac{\text{FV (Benefits)}}{\text{PV (Costs)}}} - 1$

(where 'n' equals the life of the project).

This is an accurate rate of return, but is not a substitute to maximizing NPV

7.4.6.10 Megajoule Savings/ Investment Dollar

A measure of the effectiveness of energy conservation measures proposed relative to the capital investments may be obtained from this ratio, which also serves to compare the effectiveness of these measures in different climatic zones (the greater the degree days the greater the joule savings are likely to be).

Saving in megajoules/Investment Dollar =

$$\frac{\text{Average Annual Saving in megajoules}}{\text{Total Present Value of Investment}}$$

This ratio is particularly useful for quickly assessing an order of priorities for a number of proposed retrofit projects.

7.4.7 Graphic Presentation and Interpretation

One of the most effective forms of presentation of data is a graph of cumulative NPV on the vertical scale versus time on the horizontal scale Several design alternatives can be presented on the same graph, or several economic scenarios. This form of presentation is highly effective because the interpretation of data is much facilitated with visual information displayed simultaneously for NPV's, payback periods, cross-over points, range of expected life, etc.

Where lives are unequal, or different life periods are being considered, a graph of running EUAV versus time may be plotted instead of NPV, to clearly show the effect of the period of investment.

Graphic presentations are particularly useful in analyzing present values for differing expectations of future economic conditions

7.5 Life Cycle Costing in Practice

7.5.1 Requirements for Successful Application

Life cycle costing may be practised by the individual designer, but it is most effective when part of an inter-disciplinary effort Its use as a design tool is gaining wider acceptance, although implementation is handicapped by the change in outlook required of the participants, who must be trained or sensitized to consider the long-term inter-disciplinary effects of their decisions, i e to treat design decisions as investment decisions

Successful application of life cycle cost analysis would include the following·
—participation of the owner
—participation of all design team members
—uniform cost reporting
—realistic work plan
—recognition of application problems
These items are discussed in the following sections

7.5.1.1 Client Participation

The client or his representative should be encouraged to understand the objectives as well as the mechanics of the life cycle costing process and participate actively in criteria development and decision-making This will lead to an improved relationship between the client and design team members, because the client will feel confident that the investment is being managed effectively and investment policy respected. In particular, clients should be encouraged to clearly state investment objectives and establish the financial criteria (interest rates, time horizons, etc) They should also be responsible for selecting the basis of the financial evaluation to be employed

7.5.1.2 Design Team Participation

Many decisions cannot be taken unilaterally by the architectural designer because other disciplines need to be involved For this reason, it is essential that all members of the design team contribute to the analysis

To initiate all participants to life cycle costing, a briefing session should be arranged at the earliest possible time to review the principles of the technique, the objectives, establish the role of each participant and the procedures to be followed

The initial cost plan and proposed cost reporting format should be reviewed in detail at this time to further stress the importance being attached to the economics of the project

7.5.1.3 Uniform Cost Reporting

A standard cost reporting format with sufficient detail should be adopted by all participants to facilitate analytic procedures Efforts should be made to use the standard formats used in design for reporting costs during the construction and operating phase, to facilitate the re-cycling and updating of existing data bases In Canada, the format developed by the Canadian Institute of Quantity Surveyors is widely used for design cost control purposes (see **Table 7.5.1-T_1**)

LIST OF ELEMENTS
1. Substructure
(a) Normal foundations
(b) Basement excavation and backfill
(c) Special foundations
2 Structure
(a) Lowest floor construction
(b) Upper floor construction
(c) Roof construction
3 Exterior cladding
(a) Roof finish
(b) Walls below ground floor
(c) Walls above ground floor
(d) Windows
(e) Exterior doors and screens
4. Interior Partitions and doors
(a) Permanent partitions and doors
(b) Movable partitions and doors
5. Vertical movement
(a) Stairs
(b) Elevators and escalators
6 Interior finishes
(a) Floor finishes
(b) Ceiling finishes
(c) Wall finishes
7 Fittings and equipment
(a) Fittings and fixtures
(b) Equipment
8 Services
(a) Electrical
(b) Plumbing and drains
(c) Heating, ventilation and air conditioning
9. Site Development
(a) General
(b) Services
(c) Alterations
(d) Demolition
10 Overhead and profit
(a) Site overhead
(b) Head office overhead and profit
11 Contingencies
(a) Design contingency
(b) Escalation contingency
(c) Post contract contingency

Table 7 5.1-T,
Elemental cost analysis format[1]

7.5.1.4 Work Plan Scheduling

Sufficient time must be allowed in the work plan schedule to gather the necessary information, perform the analysis and evaluations in such a way that the design process is not disrupted Timely recommendations allow decisions to be implemented over a realistic period, without causing undue delays, as no-one at early project stages, when life cycle costing is most effectively used, should have fixed positions to defend.

The objective must be to allocate sufficient time for life cycle costing during the conceptual and design development phases to establish all key design decisions, in order that design documentation can proceed without interruption

This goal may be difficult to achieve in practice because more time and attention will be required of all design team members during the pre-design stages The rewards however are substantial and, in many cases, could result in a net saving in overall effort expended

7.5.1.5 Application Problems

As with any new technique, there are bound to be problems in putting theory into practice Necessarily, this section has been devoted to establishing a framework within which life cycle costing may be applied to decision-making during facility acquisition and operation and has addressed in some detail the methods and techniques of financial evaluation, which form the basis for the calculations. Accepting that the framework and evaluation techniques are sound, the suitability of the output will then be dependent upon the reliability of the input data and it is here that the following problems will be encountered

.1 **Capital Cost Estimates:** While there is nothing finite or absolute about construction prices, most designers are familiar with construction cost levels and should be competent to estimate the capital cost components required for life cycle cost studies Data may be obtained from published sources (e.g unit price books such as Yardsticks for Costing), from contractors or from internal data sources. It is usually necessary in LCC studies to only include those items which are likely to vary between alternates and to omit the cost of any item which will remain the same between options

.2 **Operating and Maintenance Costs:** Designers are generally inexperienced in estimating the costs of operating and maintaining facilities and components thereof In addition, there are no adequate published data sources publicly available This means that information must be sought from clients, where their organizations are involved in continuing operating and maintenance of facilities, or from manufacturers and specialist firms providing maintenance services Often, where access to a reservoir of operating and maintenance cost information is available, it is often found that the data is structured in an entirely unsuitable form and cannot be re-captured for reuse In many cases, it is necessary to build up the O & M costs involved from first principles.

.3 **Obsolescence and Durability:** LCC studies often depend upon estimates of anticipated lives of entire facilities or components and, again, there is little information openly available on this subject Durability is also influenced by the level of maintenance applied Generally, information can be obtained from manufacturers and building maintenance experts The ASHRAE guide contains recommendations on service lives for various types of mechanical equipment.[2]

.4 **Salvage and Residuals:** Studies requiring estimating of salvage or residual values can also present problems. It is only reasonable to base these on today's probable values and to assume reasonable depreciation over the economic life.

.5 **Alternatives:** As most LCC studies involve the comparison of alternatives, it is worth bearing in mind that it is the cost differentials that are more important than the finite magnitude of the prices for each alternate. Decisions are likely to be taken on the basis of the range of difference in life cycle cost between options rather than on their magnitudes Analysts should therefore concentrate on measuring the differentials as accurately as possible

.6 **Forecasting:** As all LCC studies involve predictions of current and future cost levels, economic conditions, service lives, etc, the uncertainty associated with future forecasting and prediction must be a cause for concern The only certain thing about a future prediction is that it is likely to be wrong and the only way this can be sensibly handled in LCC studies is to conduct sensitivity analyses, which simply vary the forecasts and predictions for one or more element and assess whether the outcome and the ranking between alternatives changes when these elements are varied. If the rankings do not change, then it can be considered that the LCC is not sensitive to the item being considered Typically, interest, escalation and time periods are used as variables in sensitivity analyses, but there is no reason why the basic cost inputs cannot also be tested for sensitivity Due to the extensive calculations required, the use of a computer is desirable which can rapidly assess the cost effects involved

.7 **Study Cost:** One other problem is the cost and time involved in conducting life cycle cost studies during design. Traditionally, designer services do not include for such extensive economic evaluation and the funds need to be found to underwrite the expense involved It requires an enlightened owner to realize that the investment can provide savings far in excess of the cost involved

.8 **Values:** Finally, it should be borne in mind that life cycle costing is very largely a mathematical concept which will only quantify those things that can be quantified. Inevitably, other factors must be taken into account in any decision and most of these have values which cannot be reduced to dollars or numbers. Life cycle costing by itself does not make the decisions, people do, and in doing so they must be expected to use a set of values of which the mathematical results will be only part

7.6 Examples

7.6.1 Summary

The purpose of this section is to illustrate life cycle cost calculations and evaluation techniques Examples are presented under the following headings

—Optimizing Insulation
—Selection of Glazing Alternatives
—Annulized Values and Evaluation of Alternatives With Unequal Lives
—Evaluating Investment Alternatives—Benefit/Cost Ratios and Break-Even Analysis
—Sensitivity Analysis
—Depreciation, Mortgage Payments, Income Tax and Rate of Return on Investment

7.6.2 Example—Optimizing Insulation

Elements of a building can be optimized individually or in combination with other elements This simplified example illustrates how the optimum *RSI* value for a wall may be selected

Given:

Assuming that the insulating value of the exterior cladding of a building is neglible, as compared to that of the insulation itself, determine the optimum *RSI* value of the insulation based on the following parameters

—Period of evaluation—20 years
—Interest rate—10%
—Escalation rate for energy—9%
—Cost of energy—1 1¢/kW h
—Degree days—4990°C

Approach:

The following steps are taken to construct the **Table 7.6.2-T_1** and **Figure 7.6.2-1** which follow

—Select and cost wall insulation thicknesses of 50 mm, 100 mm, 150 mm and 200 mm
—Calculate annual heat loss through 1 square metre of surface
—Determine from **Table 7.0-T_6** for a 20-year period at 10% interest and 9% escalation the present value factor (CSPF—cumulative single payment factor which is 18 2)
—Calculate present values for energy savings
—Calculate total present value
—Plot insulation thickness vs total present value and draw curve through the points
—Obtain from the curve the insulation thickness for minimum present value

Analysis:

The graph (**Figure 7.6.2-1**) indicates that the optimum thickness of insulation is between 125 mm to 175 mm

The set of assumptions relates to conditions in the Ottawa area and results would be substantially different for locations in Alberta where the gas price may be less than half of the figure used or Vancouver where the degree days are considerably less

The example has not taken into account the effect on the heating and cooling plant capital and operating costs, which could be brought into the analysis with the participation of the engineering designers during the early stages of design development.

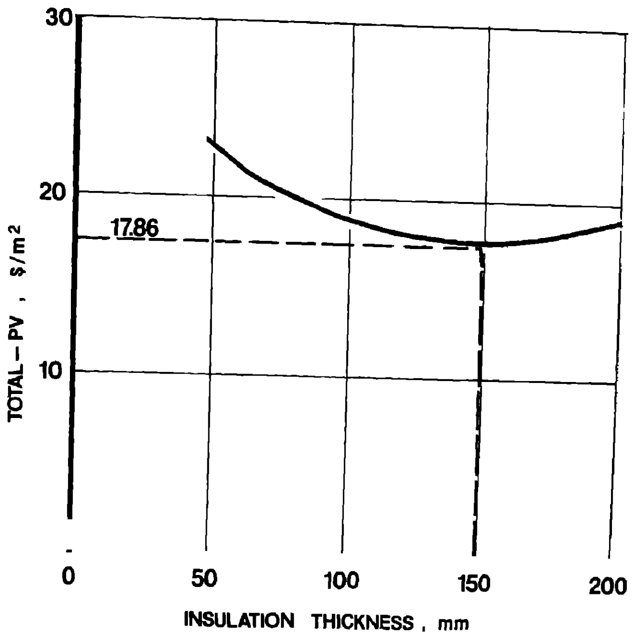

Figure 7 6 2-1
Insulation thickness optimization

OPTIMIZING INSULATION							
Insulation Thickness mm	Cost $/m²	*RSI* Factor m² °C/W	U Factor W/m²·°C	Annual* Energy Consumption kW h/m²	Annual Energy Costs $/m²	P V Energy Costs $/m²	Total P V ** Costs $/m²
50	9 04	1 76	0 57	6 35	0 75	13 67	22 70
100	11 19	3 52	0 28	3 18	0 38	6 89	18 08
150	13 34	5 28	0 19	2 12	0 25	4 52	17 86
200	15 49	7 04	0 14	1 59	0 19	3 44	18 94

* Annual energy consumption based on transmission heat losses only (no infiltration)
**Total P V Costs = Capital cost + P V Energy costs

Table 7.6.2-T$_1$
Example—Optimizing insulation, capital costs and energy costs

7.6.3
Example—Selection of Glazing Alternatives

Glazing alternatives are numerous and offer a real challenge to the designer who must reconcile energy guidelines with aesthetic or physiological requirements and also evaluate the merits of day lighting viz a viz artificial illumination (ref. Section 3.14.4). The selection of glazing materials or areas may be influenced by such

things as building overhangs, mechanical devices (e g. shutters) or control devices used for daylighting

The example which follows illustrates the economics of single, double and triple glazing in an area with 4444 degree days °C. It also illustrates the cross-over or break-even point, when the total present value of alternatives becomes equal, i e when the present value of additional savings equals the extra capital costs incurred

Given:

To evaluate the economics of single, double and triple glazing for an area with 4444 degree days °C and the following technical and economic parameters

—Period of evaluation—25 years
—Interest rate—10%
—Escalation rate for energy—9%
—Cost of energy—2¢/kW h (electrical heating)

Approach:

(A) Determine for years 5, 10, 15, 20 and 25 the present value factor for energy costs based on 10% interest and 8% escalation (CSPF—cumulative single payment factor) (**Table 7.0-T_6**)
(B) Calculate the present values for energy costs at 5-year intervals for each alternative
(C) Calculate the annual total present value at 5-year intervals for each alternative (capital cost plus present value of energy costs).
(D) Plot values for 5-year intervals and draw in curves for each selection.

Analysis:

The additional capital cost for double glazing vs single glazing is paid for in terms of present value in 9 3 years (break-even), whereas it would take 17 6 years to justify the additional cost of triple glazing vs double glazing, ref **Figure 7.6.3-1**.

As can be expected, both double glazing and triple glazing would show shorter break-even periods for locations such as Churchill, Manitoba and longer periods for locations such as Vancouver Similarly, the cost of fuel will have a marked effect on the results

PRESENT VALUES OF GLAZING ALTERNATIVES													
A	B	C	D Present Values—Energy Costs* Year					E Total Present Values** Year					
Alternative	Capital Cost	Annual Energy Cost	5	10	15	20	25	0	5	10	15	20	25
1	161 40	13 34	62 91	120 36	172 90	220 65	264 27	161 40	224 31	281 76	334 30	382 05	425 67
2	215 20	7 32	34 62	66 25	95 16	121 44	145 45	215 20	249 82	281 45	310 36	336 64	360 65
3	258 24	4 30	20 34	38 91	55 90	71 34	85 44	258 24	278 58	297 15	314 14	329 58	343 68

* Present value factors are as follows. Year 0 = 1, Year 5 = 4 73, Year 10 = 9.05, Year 15 = 13 00, Year 20 = 16 59, Year 25 = 19.87.
See CSPF factor—cumulative single payment factor, Table 7.0-T_6
**Total present value = B + D.

Table 7.6.3-T_2.
Selection of glazing alternatives, present values of glazing alternatives. (All cost figures based on \$/m²).

7.6 Examples

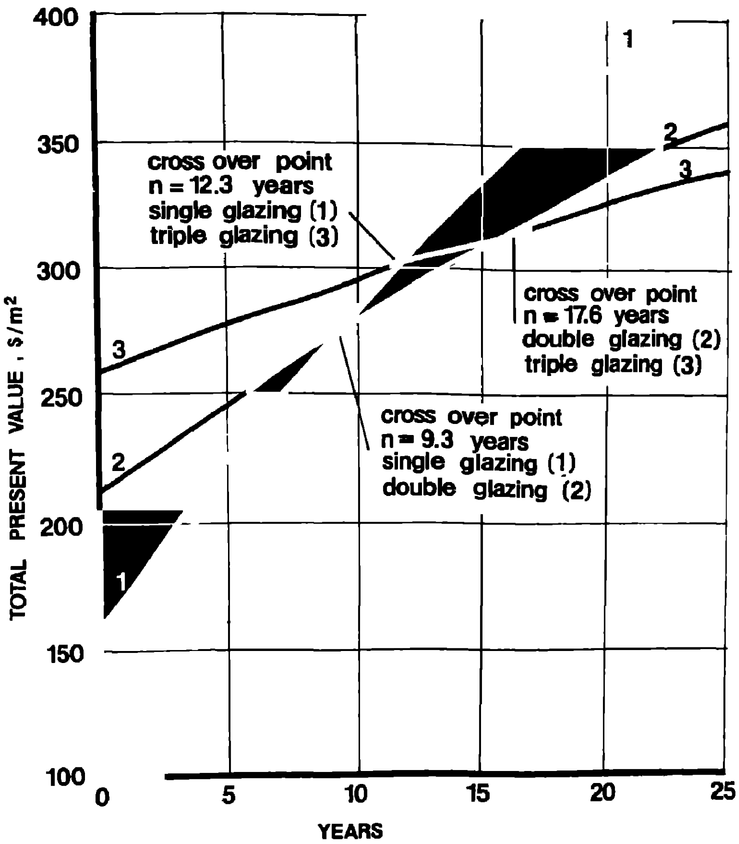

Figure 7 6 3-1
Present values of glazing alternatives

CAPITAL COSTS AND ENERGY COSTS OF GLAZING ALTERNATIVES					
Alternative	Glazing Type	Cost $/m²	U Values W/m² °C	Annual Heat Loss kW h/m²	Annual Cost of Energy $/m²
1	Single	161 40	6 3	62	13 34
2	Double	215 20	3 4	34	7 32
3	Triple	258 24	2 0	20	4 30

Table 7 6.3-T_1
Selection of glazing alternatives, capital costs and energy costs

7.6.4 Example—Annualized Values and Evaluation of Alternatives With Unequal Lives

Life cycle costs are often presented as a lump sum figure of such a magnitude that it is difficult for most people to fully understand their implications. The average person is accustomed to thinking in yearly time frames for financial matters, and presenting life cycle costs in this manner will often assist interpretation. This method of annualized presentation is also a useful tool in evaluating alternatives with unequal lives.

7.6 Examples

Given:
In **Section 7.4,** the present value of alternative A was calculated with the formula method and amounted to $23,795 40 Alternative B differed from alternative A in several respects including the evaluation period (15 years vs 20) To analyze these alternatives, present values must be annualized.

The parameters for the two alternatives are as follows

Alternative	A	B
Capital Investment . .	$10,000 00	$ 8,000 00
Interest Rate .	10%	10%
Escalation—maintenance . .	0%	0%
—materials . .	4%	4%
—energy . .	9%	9%
Time period (life expectancy)	20 years	15 years
Annual Maintenance . . .	$ 400 00	$ 450 00
Component Replacement		
—year	10	8
—current cost . . .	$ 2,000 00	$ 1,200 00
Residual Value—current cost . .	$ 1,000 00	0
Total Present Value .	$23,795.40	$19,860 00

Approach (i)
Each present value is annualized by determining the annual uniform payment that would be required to repay a principal sum equal to the present value, which in itself is one measure of the true cost to the investor

Alternative A
Uniform Annual Cost over 20 years
= $23,795 40 × UCR factor (10% interest 20 years—**Table 7.0-T_2**
= $23,795 40 × 1175 = $2,795 91

Alternative B
Uniform Annual Cost over 15 years
= $19,860 00 × UCR factor (10% interest 15 years—**Table 7.0-T_2**
= $19,860 00 × 1315 = $2,611 59

Approach (ii)
Having determined uniform annual costs, these may then be converted into equivalent lump sum present values for the shorter time period (15 years) This is a mathematical exercise to give an order of magnitude in terms of present value though it may not reflect actual conditions

Alternative A
PV = Uniform Annual Cost × UPV factor (see **Table 7.0-T_2**)
= $2,795.91 × 7 606 = $21,265 00

Alternative B
PV = Uniform Annual Cost × UPV factor (see **Table 7.0-T_2**)
= $2,611 59 × 7 606 = $19,860 00

Analysis:
In economic terms, alternative B is the evident choice because of lower capital cost, lower annual cost, and lower total present value, this choice is dependent upon a 15-year period being acceptable If the time period of alternative B is to equal 20 years, replacement costs in year 15 and residual value in year 20 must be accounted for. Should this then indicate a higher present value for alternative B (and a higher annualized value), the apparent preferred

selection would then be alternative A at a higher initial cost; however, alternative B may still prove attractive to the investor because of reduced risk due to a lower capital cost and a reduced time horizon (15 years vs 20)

7.6.5 Example—Evaluating Investment Alternatives—Benefit/Cost Ratios and Break-Even Analysis

The nature of investment alternatives may vary considerably and proper analysis may require the use of several evaluation techniques The following example is based on data developed in previous examples and demonstrates how benefit/cost ratios and break-even (or true payback) analysis can assist the decision-making process.

Given:

To determine if funds could best be invested in upgrading insulation from 50 mm to 100 mm (see Example 7 6.2), or in upgrading fenestration from single to double glazing (see Example 7.6.3)

The investments are for different locations and subject to different parameters of weather, time, energy costs and escalation

From the previous examples, the following information is available.

Insulation Upgrading—20-Year Period—Investment A

Additional cost for increasing insulation from 50 mm to 100 mm	\$2.15/m²
Decrease in total present value	\$4.62/m²
Annual energy savings	\$0.37/m²

Fenestration Upgrading—25-Year Period—Investment B

Additional cost for double glazing vs single glazing	\$53.50/m²
Decrease in present value	\$65.02/m²
Annual energy savings	\$ 6.02/m²

Approach:

The merit of each investment will be based on two factors, the benefit/cost ratio related to each specific period in question and the true payback period.

(A) *The Benefit/Cost Ratio* (B/C)

$$\text{B/C Ratio} = \frac{\text{Total Present Value—Initial Investment}}{\text{Initial Investment}}$$

$$\text{Investment A. B/C} = \frac{4.62 - 2\ 15}{2\ 15} = 1.15$$

$$\text{Investment B. B/C} = \frac{65.02 - 53.50}{53.50} = 0.22$$

(B) *True Payback Period*

True payback period is the time period during which benefits are equal to the additional capital expended. It will have to be calculated for alternative A, but can be established from the graph of total present value vs time for alternative B.

Investment A

Additional capital requirement = \$2 15/m²

Annual energy saving = 37¢/m²

Additional Capital = Cumulative Present Value Cost Savings

\$2.15 = CSPF × \$0.37

$$\text{CSPF} = \frac{2.15}{0.37} = 5.8$$

7.6 Examples

From Table 7.0-T_6 at 9% escalation, the CSPF factor for year 6 is 5 81, indicating that true payback would occur some time during the end of year 6

Investment B
Additional capital requirement = \$53 50/m²
Annual energy saving = \$6 02/m²
Additional Cost = Cumulative Present Value of Cost Savings
53 50 = CSPF × 6 02

$$CSPF = \frac{53\ 50}{6.02} = 8\ 9$$

From Table 7.0-T_6 at 9% escalation, the CSPF factor for year 9 is 8 6 and 9 5 for year 10, indicating that the true payback period would occur some time during year 10 (this also agrees with the graph which shows 9 3 years as the break-even point)

Analysis:
Investment A indicates a benefit/cost ration of 1 15 and a payback period of 6 years, investment B shows a much lower Benefit/ratio of 0 22 and a 10-year payback period

These factors clearly indicate that upgrading insulation is a much better investment than upgrading glazing because of the higher cost-benefits per dollar invested and also because of the greatly reduced risk, i e. a 6-year payback instead of 10 years The lesser payback may often be favoured at a lower benefit/cost ratio when there is a substantial difference in payback periods

7.6.6 Example—Sensitivity Analysis

The problems of establishing the future values of the inputs to LCC studies with any degree of accuracy can be partially resolved by investigating the effect of possible variations in the parameters, such as capital costs, time period chosen, interest rates, escalation rates, etc The following example illustrates the effect of variations in interest rates on the results obtained

Given:
Mechanical equipment costing \$500,000 is to be put into a building The system will consume \$50,000 annually in fuel, and will require two operators at \$12,500 each, or a total of \$25,000, all estimated at today's costs The system is fairly standard and well-known, and is expected to have a life of 20 years A new piece of equipment however has now just become available It would cost \$75,000 to acquire, but promises to save \$10,000 annually in fuel costs As the equipment is new, however, the company that manufactures it insists on a service contract for maintenance and inspection This would cost \$5,000 annually plus escalation.

The manufacturer claims the equipment will last 20 years, but this is uncertain, life of the equipment is probably between 10 and 20 years With the new equipment, total costs will be \$575,000 initial, \$40,000 annual fuel and \$30,000 annual labour.

Is it worth investing in the new piece of equipment or not? The current economic outlook indicates that escalation rates of 12% and 8% per annum can be expected for fuel and labour costs respectively. An optimistic expectation might be 10% and 7%, while a pessimistic outlook indicates 14% and 9% escalation rates respectively

Analysis:
The $75,000 piece of equipment will save $5,000 net in today's costs annually, indicating a simple payback of 15 years This seems viable as life may be as much as 20 years.

The building owner is a government agency (no mortgage, no income tax) and the relevant interest rate is 10% A table of present value factors can be selected, as follows

Year, 'n'	Present Value Factors		
	Optimistic e = 10%	Median e = 12%	Pessimistic e = 14%
5	5	5.28	5.57
10	10	11 06	12.23
15	15	17.38	20.20
20	20	24 30	29 72

Table 7 6 6-T_1
Scenario of present value factors for fuel

Year, 'n'	Present Value Factors		
	Optimistic e = 7%	Median e = 8%	Pessimistic e = 9%
5	4 61	4 73	4 87
10	8.62	9 05	9 51
15	12.11	12 99	13.95
20	15.15	16 59	18.20

Table 7 6 6-T_2
Scenario of present value factors for labour

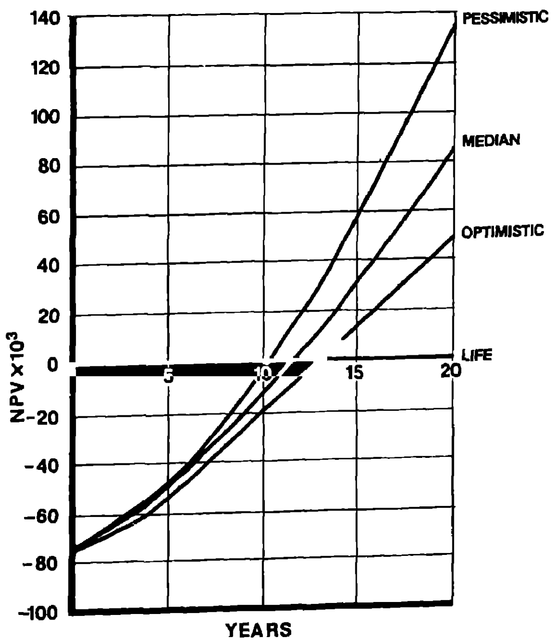

Figure 7 6.6-1
Sensitivity analysis.

With these factors, running NPV's at 5 year intervals can be calculated as follows:

Year, 'n'	Net Present Value, NPV, $		
	Optimistic	Median	Pessimistic
0	− $75,000	− $75,000	− $75,000
5	− 48,050	− 45,850	− 43,650
10	− 18,100	− 9,650	− 250
15	14,450	33,850	57,250
20	49,250	85,050	131,200

Table 7 6 6-T_3
Scenario of present value at five year intervals

(For example, for year 20 under the median scenario, NPV = 85,050 = −75,000 − 16 59 × 5000 + 24.30 × 10,000)
The following graph (**Figure 7.6.6-1**) shows that the investment has a positive NPV at the end of the claimed life of 20 years. A positive NPV however can only be guaranteed if the equipment lasts for at least 13 years. If the equipment does not last at least 10 years, then even under high, pessimistic escalation conditions the investment will not be viable

7.6.7 Example—Depreciation, Mortgage Payments, Income Tax and Rate of Return on Investment

As indicated previously, complex situations can best be analyzed with the flow method calculation technique The following is a good example of how the mathematics of accounting for depreciation, mortgage payments and taxes are integrated simply into present value calculation procedures A speculative investor in the case presented in **Section 7.6.6** invests as equity 10% of the capital funds required, and calculations are presented to determine the rate of return on his investment

Given:

The extra $75,000 capital expenditure outlined in **Section 7.6.6** is being considered by a speculative builder whose marginal tax rate is 30% and cost of capital is 15% due to the speculative nature of the project Of the initial $75,000 required, 10% ($7,500) will be financed by the builder and 90% ($67,500) will be raised through a 15 year mortgage at 11½% interest The equipment will be depreciated at 20% per annum on a declining basis and escalation rates of 12% for energy and 8% for labour will be used throughout the 15-year analysis period (median scenario)

Approach·

The flow method is employed to calculate the cumulative NPV after appropriate adjustments for depreciation, mortgage expenses and income tax. The notes shown at the base of the table are self-explanatory and will allow the calculations to be followed step-by-step. It is evident from the numerous figures in the table that the use of a computer program would reduce the time required to execute such calculations

Analysis:

As can be seen from column J of **Table 7.6.7-T_1**, there is a positive NPV of $12,415.00 at year 15, and true payback occurs in year 9 (NPV = 0) Had this been a government project totally financed from equity (no mortgage financing), the initial investment would be $75,000 instead of $7,500 and the true payback period would have been extended beyond 9 years. This indicates that the

investment is more viable for the speculative builder than for the government agency because the former can take advantage of mortgage financing at a rate lower than the cost of capital and depreciation expenses that are heavily front loaded.

The rate of return on the investor's equity can also be readily calculated. The \$7,500 investment in year 0 has resulted in a net present value of \$12,415.00 after 15 years. To determine the rate of return on his investment, the following method is followed.

—The future value (FV) of the present value is established, i.e. the value in 15 years of \$12,415.00 invested at 15% (cost of money to the builder)

$$FV = \$12,415\ 00 \times \text{SCA factor } (\textbf{Table 7.0-T}_4)$$
$$= \$12,415,00 \times 8\ 137 = \$101,020\ 00$$

—This future value is equal to the \$7,500 investment × the SCA factor determined for the appropriate interest rate (rate of return on his investment).

$$FV = \$7,500.00 \times SCA = \$101,020\ 00$$
$$SCA = \frac{101,020}{7,500} = 13.47$$

From interest tables, for a 15-year period

SCA at 15% interest = 8.137
SCA at 20% interest = 15.41

Therefore, for an SCA factor of 13.47, the actual rate of return on the investment would be in the order of 18%.

Year 'n'	A Initial Investment	B Mortgage Payment	C Fuel Saving	D Labour Cost	E NCF	F Principal Expense	G Depreciation	H After-Tax NCF	I Annual PV	J Total NPV
0	7,500	—	—	—	−7,500	—	—	−7,500	−7,500	−7,500
1	—	9,647	11,200	5,400	−3,847	1,884	15,000	1,242	1,080	−6,420
2	—	9,647	12,544	5,832	−2,935	2,101	12,000	915	692	−5,728
3	—	9,647	14,049	6,299	−1,897	2,343	9,600	849	558	−5,170
4	—	9 647	15,735	6,802	−714	2,612	7,680	1,021	584	−4,586
5	—	9,647	17,623	7,347	629	2,913	6,144	1,410	701	−3,885
6	—	9,647	19,738	7,934	2,157	3,248	4,915	2,010	869	−3,016
7	—	9,647	22,107	8,569	3,891	3,622	3,932	2,817	1,059	−1,957
8	—	9,647	24,760	9,255	5,858	4,038	3,146	3,833	1,253	−704
9	—	9,647	27,731	9,995	8,089	4,503	2,517	5,067	1,440	736
10	—	9,647	31,058	10,795	10,616	5,020	2,013	6,529	1,614	2,350
11	—	9 647	34,786	11,658	13,481	5,598	1,611	8,241	1,771	4,121
12	—	9,647	38,960	12,591	16,722	6,245	1,288	10,218	1,910	6,031
13	—	9,647	43,635	13,598	20,390	6,959	1,031	12,495	2,031	8,062
14	—	9,647	48,871	14,686	24,538	7,760	825	15,096	2,133	10,195
15	—	9,647	54,736	15,861	29,228	8,652	660	18,062	2,220	12,415

A 10% of \$75,000, not subject to tax
B M = \$67,500, MPF = 0 1429
C $(1+e)^n \times \$10{,}000 = SCA \times \$10{,}000$, 'e' = 12%
D $(1+e)^n \times \$5{,}000 = SCA \times \$5{,}000$, 'e' = 8%
E C − (B + D) − A
F $= (MPF - m)(1+m)^{n-1}$, m = 11 5%
G $= \$75{,}000 \times a(1-a)^{n-1}$; a = 0 20 or 20%
H $= (1-t)E + t(G-F)$; t = 30% = tax rate
I $= H/(1+i)^n = H \times SPV$, 'i' = 15%
J = Cumulative I

Table 7.6.7-T$_1$
Example—Depreciation, mortgage payments, income tax and rate of return on investment flow method calculations

Text References

7.0 Energy Economics

7.5 Life Cycle Costing in Practice

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Energy Overview

Terminology and Heat Equivalent

In discussing energy resources it is necessary to differentiate between primary and secondary energy. Primary energy is the available energy content of a natural resource, whereas secondary energy is defined as the amount of energy delivered to the final consumer. The difference between the two is the energy lost in conversion and in the process of supply, including transmission

Energy supplies are either renewable or non-renewable, with renewable supplies being derived from sources which are perpetual or replenishable and have life spans, under stable conditions, comparable to that of the solar system Solar, biomass, geothermal, wind, ocean tides and waves are examples of renewable sources

In order to be able to compare the potential energy of an energy form, each can be converted into an equivalent heat value **Table (i)** gives approximate heat equivalents for a variety of energy forms.

HEAT EQUIVALENT OF VARIOUS ENERGY FORMS

Energy form	Heat value gigajoules
Petroleum (per cubic metre)*	
Crude oil	38 49
Liquefied petroleum gases	27 17
Motor gasoline	34 65
Aviation gasoline	33 52
Aviation turbo fuel	35 91
Kerosene	37 67
Diesel and light fuel oil	38 68
Heavy fuel oil and still gas	41 70
Petroleum coke	42 33
Natural gas	
(per thousand cubic metres)	37 23
Coal (per tonne)	
Anthracite	29 53
Imported bituminous	29 99
Canadian bituminous	29 30
Sub bituminous	19 76
Lignite	15 35
Coke (per tonne)	26 15
Coke oven gas	
(per thousand cubic metres)	18 62
Electricity (per megawatt hour)	3 60

* at 15 C

Table (i)
Approximate heat equivalents for a variety of energy forms

Energy Supply

A word of caution is justified before discussing potential energy supplies this Handbook has utilized recent and, it is believed, reliable sources in order to estimate potential supplies of energy. However, estimates differ, according to the source, and new and potentially large sources are liable to be discovered almost daily. Consequently the whole question of energy supply is flexible and dynamic and the figures quoted herein could well be out-of-date within a short period of time.

The World Perspective

The world's nations, including Canada, continue to rely upon oil to meet a major portion of their energy demands, despite the fact that future supplies of oil are unpredictable. By relying upon a few large sources of oil, importing nations face the twin jeopardies of

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world demand becoming greater than world production, and of an economic and political reliance upon the source to continue with the supply, even assuming that increased production capacity from the source area is possible

Without large discoveries of new oil reserves, or changes in demand patterns, world energy supply could well fall short of demand by as early as the mid-1980's **Figure (i)** indicates the crude oil supply and demand forecasts for noncommunist world through 1990 (currently the Sino-Soviet bloc countries produce approximately 22% of the world's crude oil supply, and hold 15% of the estimated reserves)

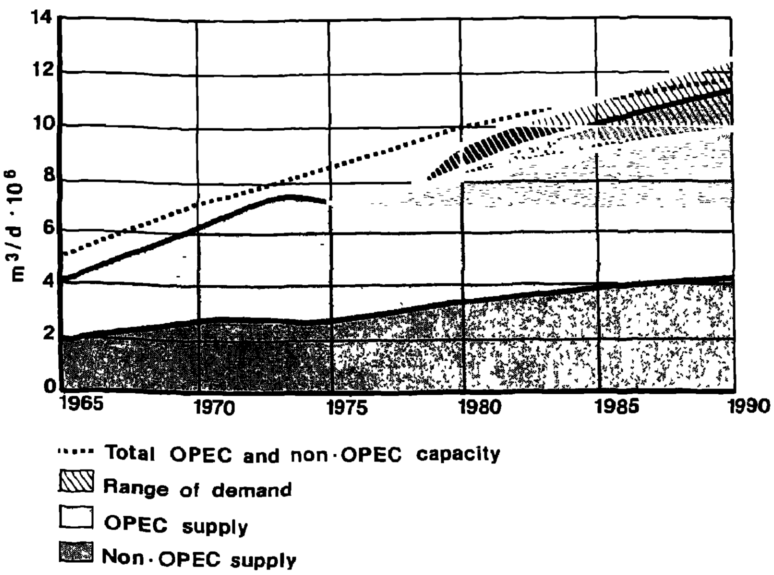

Figure (i)
Crude oil supply and demand for the non-communist world[1]

Canadian Energy Supplies

Oil: Total Canadian production of crude oil and its equivalents was approximately 250 600 m^3/d (cubic metres per day) in 1978, consisting of 199 600 m^3/d of conventional crude oil, 8 800 m^3/d of synthetic crude and 42 100 m^3/d of natural gas liquids[2] Of course, Canada is a net importer of oil, with net imports totalling approximately 26 100 m^3/d in 1978

One estimate of the future Canadian supply and demand for oil is shown in **Figure (ii)** where it can be seen that domestic shortfalls are forecast, even under the most optimistic scenarios, between now and the mid 1990's

Gas: The Canadian production of natural gas was some 189 900 000 m^3/d in 1978, down approximately 5 5% from 1977[3]. Unlike oil, Canada is a net exporter of natural gas with approximately 68 400 000 m^3/d being exported to the U S in 1978 The National Energy Board's estimates of potential natural gas supplies in conventional areas of Canada are 50×10^{10} m^3 in British Columbia, 350×10^{10} m^3 in Alberta, 8.5×10^{10} m^3 in Saskatchewan and approximately 3.0×10^{10} m^3 in other provinces About two-thirds of this has been found to date, and 22% has been produced[4].

Figure (iii) illustrates the National Energy Board findings that Canada can meet its own gas demand together with authorized exports, at least until the 1990's

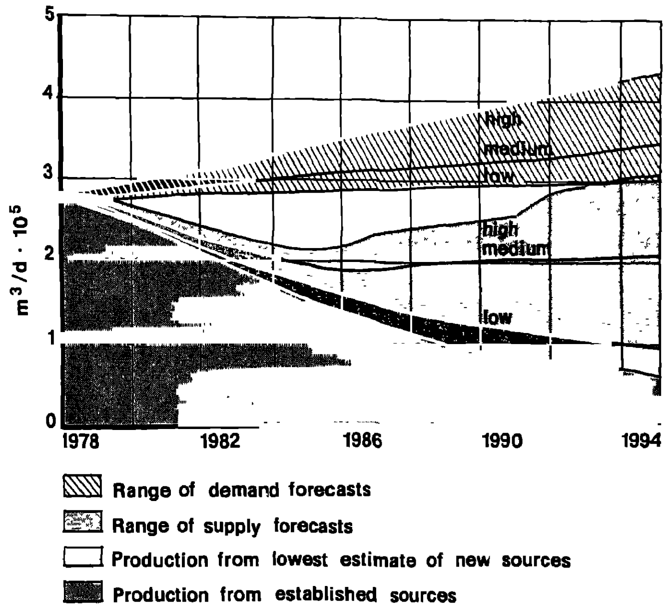

Figure (ii)
Canadian oil supply and demand outlook [5]

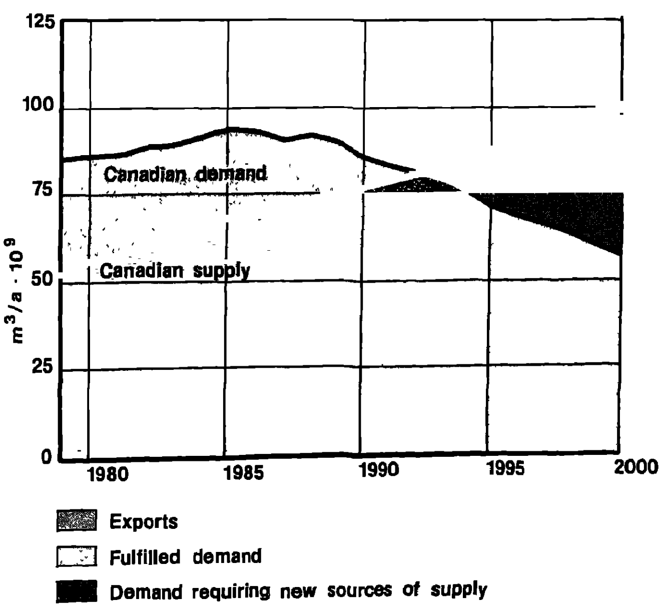

Figure (iii)
Canadian natural gas supply and demand outlook.[6]

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Electricity: The major sources of electrical energy in Canada in 1978 were hydro power (70 1%), fossil fuels (21 4%) and nuclear power (8 5%) when Canada's installed capacity to generate electricity was estimated at 74 153 MW[7]. With debate now it is somewhat difficult to predict, over the long term, the type and capacity requirements of generating equipment However, up to the 1990's the situation is more clearly defined In fact, the Ministry of Energy, Mines and Resources has prepared a map, **Figure (iv)**, designating the sites for major expansion in generating capacity in Canada between 1978 and 1990

Coal: Canadian coal production in 1978 was 30 3 Mt (Megatonnes) with imports and exports approximately balancing each other at approximately 13 Mt each[8] Of this about 73% was used to produce 14% of the nation's electrical power Coal reserves in Canada are believed to be at least 5400 Mt.

Uranium and Nuclear Energy: To meet the existing installed capacity of nuclear generating plants approximately 770 t of uranium are required annually

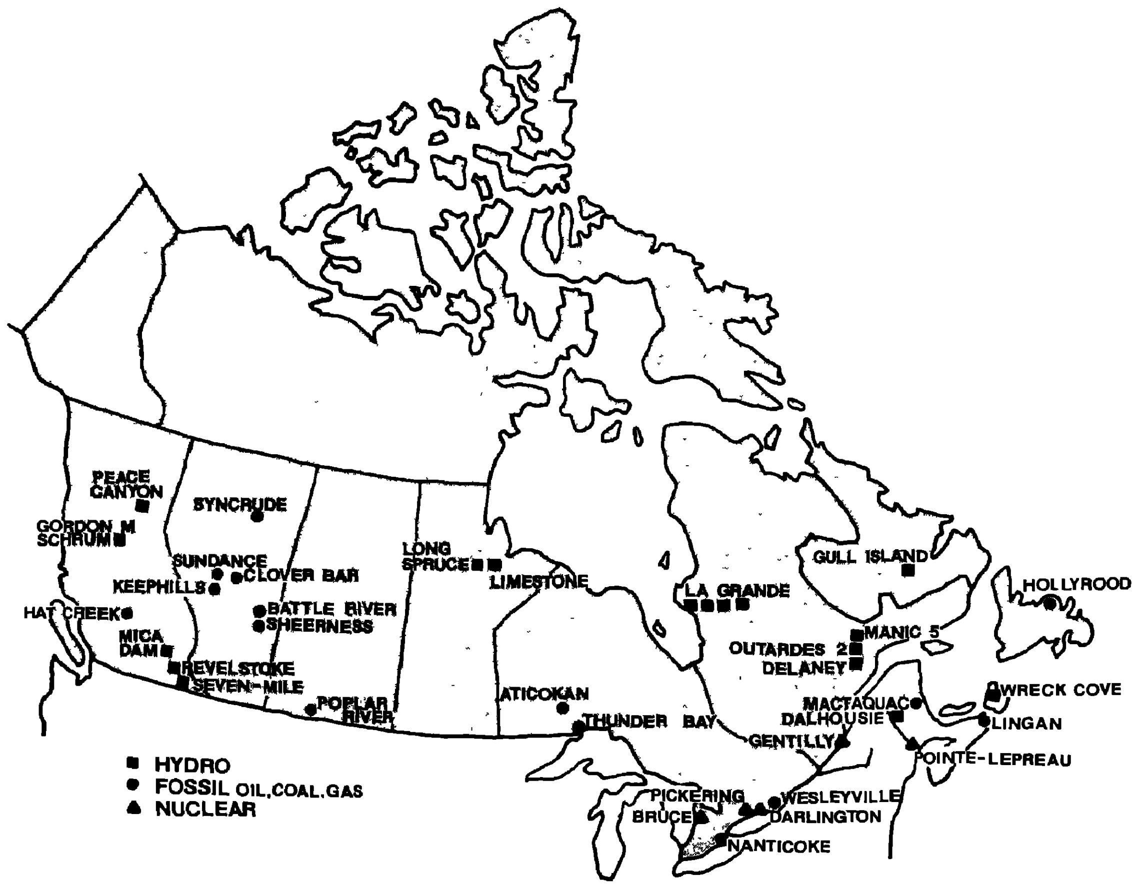

Figure (iv)
Sites for major expansion in electrical generating capacity 1978-1990[9]

Production of uranium in 1978 was estimated at 6800 t from six producers. In 1978 the Uranium Resource Appraisal Group (URAG) of Energy, Mines and Resources, Canada (EMR) published its fourth annual (1977) assessment of Canada's mineable uranium resources summarized in Table (ii).

CANADA'S MINEABLE URANIUM RESOURCES		
	Tonnes U Contained in Ore Mineable at Uranium Prices up to	
Resource Category	$110,000/t U	$160,000/t U
(1) Measured	78 000	82 000
(2) Indicated	94 000	107 000
(1) + (2) = Reasonably Assured	172 000	189 000
(3) Inferred	243 000	318 000
(4) Prognosticated	161 000	388 000
(3) + (4) = Estimated Additional	404 000	706 000

*$1 10/kg U (Canadian dollars) was the estimated uranium market price in September 1977, at the commencement of the assessment

Table (ii)
1977 Estimates of Canada's mineable uranium resources[10]

Year of Study	Scenario or Projection	Primary Energy Requirements in the Year 2000 10^{18} J*	Rate of Growth 1975-2000 %	Secondary Energy Requirement in the Year 2000 10^{18} J*	Rate of Growth 1975-2000 %	Source
1975	Energy Balance	28 0	4 7	20 2	4 5	EMR An Energy Policy for Canada†
1975	High Protection	20 9	4 2	16 2	3 9	Science Council E R Q Stoian a forthcoming background study†‡
	Standard Projection	15 6	3 4	12 1	3 1	
1976	Low Price Scenario	23 3	4 4	15 0	3 7	EMR An Energy Strategy for Canada§
	High Price Scenario	21 0	4 0	13 5	3 3	
1977	Energy Conservation Scenario	12 9	2 0	7 2	1 2	EMR Energy Conservation in Canada§‖
1978	Illustrative or Reference Demand	16 0	2 8	10 0	2 4	EMR LEAP Energy Futures for Canadians

Table title: NATIONAL ENERGY REQUIREMENTS

* In 1975 the national energy consumption was 7 9 × 10^{18} J of primary energy and 5.3 × 10^{18} J of secondary energy
† Figures for 1975 are interpolated
‡ A review of energy requirements is made in the forthcoming background study
§ Figures for 2000 are extrapolated
‖ Gross-primary and end-use secondary figures were used

Figure (iii)
Estimates of national energy requirements.[11]

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Renewable Energy Resources:

—Biomass, the energy value of plant and animal matter released by biological or chemical conversion, accounts for 3 5% of Canada's primary energy in the form of wood combustion

—Solar Although it is forecast that solar energy may be the economic choice for domestic water and space heating within a decade, no reliable figures for existing supply are available

—Other potential renewable sources are geothermal, wind and tidal power.

Energy Demand

National Energy Requirements

The Science Council of Canada[12] recently presented estimates of future national energy requirements based on various energy demand scenarios developed from different studies

These estimates and sources are shown in **Table (iii)** where it can be seen that energy requirements in the year 2000 could vary by over 100%, depending upon which scenario is assumed

Canada's current rate of energy consumption, on a per capita basis, is one of the highest in the world, and is steadily rising Total consumption in 1978 was estimated at some 9085×10^{12} kJ[13], with industrial and transportation uses accounting for some 61 5% of that

Figure (v) indicates 1976 Statistics Canada estimates for domestic consumption of secondary energy

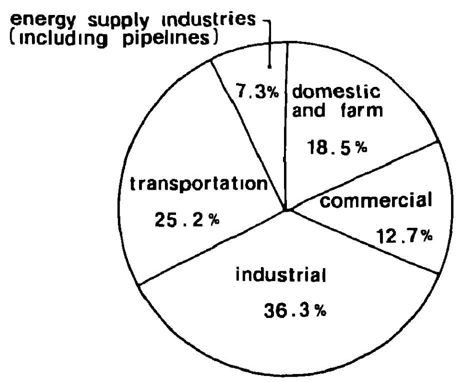

Figure (v)
Consumption of secondary energy (including biomass)[14]

Regionally, Ontario used approximately 35% of the energy consumed in Canada followed by Quebec with 26%, the Prairie provinces with 20%, British Columbia and the Territories with 11%, and the Atlantic provinces with 8%.

Demand for Each Energy Form

In the section below, current consumption of each energy form is stated and estimates of future demand are quoted from specific studies. However, the interrelationship between energy forms is so close that the demand for one form, could rise dramatically if another form, proved difficult and costly to develop to its potential Con-

sequently the individual demands must be tempered by judgement and may well vary dramatically should currently unforeseen events occur.

Oil: Canadian consumption of crude oil and natural gas liquids was some 293 000 m^3/d in 1978 This represented a growth rate of some 2 4% over 1978, thanks largely to the effects of pricing and strengthened conservation efforts[15]

Figure (ii) shown earlier, illustrates the National Energy Board's estimated demand for oil to the mid 1990's based on a range of low, medium and high demand forecasts It can be seen that by 1995 Canadian demand for oil will likely be between approximately 318 000 m^3 to about 445 000 m^3/d

Gas: In 1978, Canadians used an estimated 112 100 000 m^3 of natural gas per day[16] while the National Energy Board estimates that by about 1993 the demand for natural gas will require new sources of supply. This demand outlook is illustrated in **Figure (ii).**

Electricity: The Science Council[17] has stated that, as a percentage of energy consumption, electricity will increase significantly by the year 2000 and could represent 40% of Canadian energy needs Of this the greatest *new* demand for electrical energy in Canada is likely to arise within the transportation sector where Canadian railways are reappraising electrification In addition new light rapid transit (LRT) and commuter rail facilities will increase the need for electricity

Coal. Consumption of coal in Canada in 1978 was some 32 Mt and future demands for coal are closely related to the availability of oil and the use of nuclear generators Failure of supplies from either of the latter sources could result in a resurgence in the demand for coal which is currently relatively stable.

Uranium and Nuclear Energy: The debate over nuclear energy continues and it is difficult to predict what the demand for nuclear power will be, mainly because of political and safety concerns However, a significant commitment was made in 1978 when Ontario approved long-term contracts for the delivery of some 76 000 t of uranium to Ontario Hydro In addition major projects are underway which will double Canadian output of uranium by 1985

Reducing Demand

Efficient use of energy is imperative since increasing prices for all forms of energy are not only affecting the disposable income of individuals and the profitability of companies but are, according to a majority of economists, contributing significantly to inflation A reduction in demand must therefore be a major aspect of any energy policy if it is to be successful

In its energy strategy published in 1976 the Government of Canada articulated a goal to reduce the average rate of growth of energy use in Canada, over the next ten years, to less than 3 5% per year from the approximately 5.1% per year growth rate experienced over the past 15 years(1). More recently, in its Energy Conservation program published in 1977, it illustrated that a lower primary energy growth rate of 2% per year appeared feasible

In their June 1979 report[18], the Science Council of Canada recognized that if Canada is to (a) avoid the economic disruptions caused by large imports of increasingly expensive oil, (b) minimize the impact of politically motivated interruptions of this dominant

resource, and (c) systematically develop long-term sources and technologies leading to self-reliance, it must:

—in the short term, find effective ways to minimize oil imports by conservation, substitution by alternative fuels, improved energy conversion processes, and more effective recovery of other hydrocarbon resources

—in the long term, explore those energy opportunities most appropriate to satisfy Canada's projected match of requirements and resource contributions (a number of energy use and supply technology options must, therefore, be studied simultaneously)

This particular report made a series of recommendations on research which should be conducted to increase the supply of energy However a rational and complete energy strategy must give equal emphasis to reducing future demand Only by working from both ends of the spectrum—increasing domestic supply and reducing domestic demand—can energy self-sufficiency be realistically achieved. It is with the second of the goals in mind that this Handbook has been written.

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